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EVALUATION OF RADON 222 NEAR URANIUM TAILINGS PILES

Bureau of Radiological Health
Rockville, Maryland

March 1969

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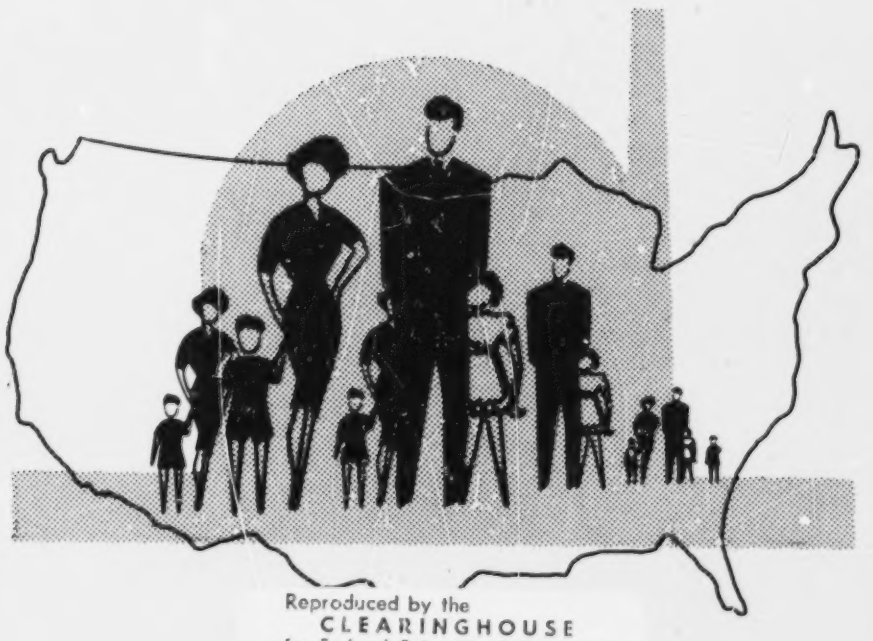

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DER 69-1 Evaluation of Radon 222 Near Uranium Tailings Piles

DER 69-1

EVALUATION OF RADON 222 NEAR URANIUM TAILINGS PILES

Final report of joint project of the U. S. Public Health Service and the U. S. Atomic Energy Commission in cooperation with the State Health Agencies of Colorado and Utah

March 1969

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
Environmental Control Administration
Bureau of Radiological Health
Rockville, Maryland 20852

FOREWORD

A one year research program to evaluate radon 222 near uranium tailings piles was undertaken in June 1967 under a joint agreement between the United States Atomic Energy Commission and the United States Public Health Service in cooperation with the Colorado State Department of Public Health. The objective of this joint project is to provide technical advice and assistance to States and industries in evaluating public health aspects of atmospheric concentrations of radon 222 in the vicinity of uranium tailings piles. The study also was directed to determine the effectiveness of stabilization and containment of uranium tailings piles in controlling radon emanation.

The technical report series of the Division of Environmental Radiation is used to publish the results of research projects and technical evaluations of nuclear facilities. The reports are distributed to State and local radiological health program personnel, Bureau technical staff, Bureau advisory committee members, university radiation safety officers, libraries and information services, industry, hospitals, laboratories, schools, the press, and other interested individuals. These reports are also included in the collections of the Library of Congress and the Clearinghouse for Federal Scientific and Technical Information.

I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

Charles L. Weaver
Director, Division of
Environmental Radiation
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Martin B. Biles
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Grateful appreciation is expressed by the U.S. Atomic Energy Commission and the U.S. Public Health Service to many individuals of the Foote Mineral Company, Vitro Corporation of America, Climax Uranium Company, Lucius Pitkin, Inc., the health departments of the States of Utah and Colorado, and the Environmental Sciences Services Administration. Without their help, this study would not have been possible.

PREPARATION OF THIS REPORT

This report was prepared at a project review meeting held at the State Division of Health, Salt Lake City, Utah, November 19, 1968, and was based on a technical paper by Dr. S. D. Shearer, Jr., and Dr. C. W. Sill. The following attended the meeting:

Dr. Grant S. Winn, Utah State Division of Health, Salt Lake City
Mr. Dennis R. Dalley, Utah State Division of Health, Salt Lake City
Mr. R. D. Siek, Colorado State Department of Health, Denver
Dr. R. J. Augustine, Bureau of Radiological Health, PHS, Rockville, Maryland
Mr. P. B. Smith, BRH, PHS, Region VIII Office, Denver
Dr. S. D. Shearer, Jr., Southwestern Radiological Health Laboratory, BRH, PHS, Las Vegas
Mr. Pope A. Lawrence, National Air Pollution Central Administration, Washington, D.C.
Mr. Frank McGinley, U.S. Atomic Energy Commission, Grand Junction Office, Colorado
Mr. Warren E. Bush, Lucius Pitkin, Inc., Grand Junction, Colorado
Dr. Claude W. Sill, Health Services Laboratory, Idaho Operations Office, U.S. Atomic Energy Commission
Mr. Don F. Harmon, U.S. Atomic Energy Commission, Washington, D.C.
Mr. Harvey F. Soule, U.S. Atomic Energy Commission, Washington, D.C.

EVALUATION OF RADON 222 NEAR URANIUM TAILINGS PILES

INTRODUCTION

The impact of uranium milling operations on the air and water environment has been studied by a number of Federal and State agencies as well as private industry since the mid-1950's. Most of the investigations to date have been concerned with potential water pollution from milling operations. Increased attention has been focused during the past several years on the atmospheric effects of such operations, particularly the influence of unstabilized mill tailings piles on the atmospheric radioactivity levels in surrounding communities.

Limited atmospheric grab sampling in the vicinity of several uranium mills in 1966 indicated that the radon 222 emanation from the tailings might be increasing environmental levels significantly; however, the sampling program was minimal and the results were limited in their interpretation. Because of increasing public interest, a more elaborate joint study was initiated.

OBJECTIVES

Under a joint agreement between the U.S. Atomic Energy Commission and the U.S. Public Health Service, a project was begun in June 1967, in cooperation with the Colorado Department of Public Health and the Utah State Division of Health to evaluate the public health aspects of atmospheric concentrations of radon 222 in the vicinity of uranium tailings piles. Specific objectives of this project were to:

1. Develop techniques for taking integrated air samples for radon near uranium tailings piles.

2. Evaluate atmospheric concentrations of radon in areas near tailings piles as an index of radiation exposure to the population.

3. Determine the effect of stabilization and covering on the emanation of radon gas from tailings piles.

4. Develop joint recommendations (or guidelines), if necessary, to control exposures based on radon concentrations found.

5. Make the information available to States through technical assistance and published reports.

The National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP) have developed criteria for individuals occupationally exposed to radon 222 (1,2). The maximum permissible concentration (MPC_a) of 30 pCi/liter for a 40-hour week and 10 pCi/liter for a 168-hour week have been set for occupational exposure to radon 222 and its daughter products in equilibrium. It is permissible to adjust these concentration limits if it is found that radon 222 is not in equilibrium with its daughter products.

The NCRP (NBS Handbook 69, page 6) states that the maximum permissible average body burden of radionuclides in persons outside of the controlled area and attributable to the operations within the controlled area shall not exceed one-tenth of that for radiation workers (that is, based on continuous occupational exposure for a 168-hour week), and that this recommendation is primarily for the purpose of keeping the average dose to the whole population as low as reasonably possible and not because of the likelihood of specific injury to the individual.

Recommendations of the ICRP state that the annual radiation dose limits for members of the public shall be one-tenth of the corresponding annual occupational values for continuous exposure. Application of these recommendations to the 168-hour value for occupational exposure to radon 222 with daughter products present at equilibrium concentrations leads to a value of 1 pCi/liter for continuous exposure to individuals in the general population. This concentration is in addition to natural background radon levels. Thus, for the purpose of this study, 1 pCi/liter of radon 222 above background in air was used as the screening value below which no further attention would be given to the concentrations involved. Should data obtained from the survey indicate average annual exposures to concentrations of radon 222 in air in excess of 1 pCi/liter above background, it would be necessary to consider the extent of equilibrium between radon and its daughter products.

While Federal regulations generally permit average concentrations of radon 222 up to 3 pCi/liter in air leaving the boundary of a restricted area of a licensed facility, quantities permitted to be released from the restricted area are subject to reduction if it appears that they might result in the exposure of a suitable sample of an exposed population group to average concentrations of radon 222 in excess of 1 pCi/liter (3).

DESCRIPTION OF STUDY

Station Locations

In order that the study areas reflect conditions at both operating and inactive uranium mills, locations were chosen initially at Grand Junction, Colo. (operating mill, uncovered tailings), Durango, Colo. (inactive mill, uncovered tailings), and Monticello, Utah (inactive mill, covered tailings). Salt Lake City, Utah was added to the study in October 1967. The Salt Lake City tailings are uncovered, and the mill was closed in July 1968. At each of these study areas, a number of sampling sites were selected that were representative of onpile, near-pile, and general community conditions. Locations were chosen taking into consideration the prevailing wind patterns, population densities, geographical factors, and so forth. At Grand Junction, 25 sampling sites were chosen with five being located directly on the tailings pile: at Durango, eight sites were chosen, two of which were on the tailings pile; at Salt Lake City, 12 sites were chosen with one station being on the tailings pile and another immediately adjacent; and at Monticello, 12 stations were established, four of which were on the tailings area. At the four study areas a total of 57 sampling sites were selected, 12 of which were directly over tailings material, and one immediately adjacent.

Sampling Techniques and Frequency

The equipment used to collect the samples is described in detail in appendix 1. A small aquarium aerator pump forces filtered air through a precision needle valve into a 40-liter laminated Mylar bag at 10 ml/min to give a volume of 30 liters

in each 48-hour sampling period. At each sampling location, the pump and bag were placed in a protective weather enclosure. The pump inlet was 3 feet above the ground or the tailings. Sampling was carried out over a 48-hour period in order that 2 diurnal cycles might be covered. The sampling schedule was designed so that each location would be sampled once every 3 weeks over a 12-month period. By sampling in this manner, any bias because of daily or seasonal meteorological variations would be minimized.

Analytical Procedures

After an extensive intercomparison period, one-half of the samples collected were analyzed at each of the participating laboratories (AEC Health Services Laboratory, Idaho Falls; PHS Southwestern Radiological Health Laboratory, Las Vegas). Samples were shipped to the laboratories by the most expeditious means to minimize corrections for radon decay. The analytical technique consisted of passing a known volume of sample through a gas-separation apparatus and absorbing the radon on activated charcoal at low temperature. The charcoal was then heated and the radon transferred to an alpha-sensitive scintillation cell for subsequent counting. The statistical uncertainty was generally less than 15 percent at the 95 percent confidence level.

In order to determine the agreement between the two laboratories' results, all samples collected during the first 6 weeks of the study were analyzed in duplicate at both laboratories. A paired observation test demonstrated that the differences between the laboratories' results were in agreement, within the uncertainties of the counting statistics involved. After this initial intercomparison, about 5 percent of the remaining samples were analyzed in both laboratories as a continuing cross-check on quality control. All counting data were corrected for radioactive decay to the midpoint of the respective sampling periods; in addition, the concentrations as determined in the laboratory were calculated to the mean annual pressure and temperature at each of the study locations which were: Grand Junction, 638 mm, 11° C.; Durango, 599 mm, 8° C.; Monticello, 587 mm, 8° C.; and Salt Lake City, 654 mm, 11° C.; respectively.

RESULTS

During the period of sampling for this program, a total of 892 samples were collected, 209 of which were onpile samples and 683 were offpile samples. The numbers of onpile and offpile samples by study area are: 85 and 320 in Grand Junction; 30 and 82 in Durango; 31 and 150 in Salt Lake City; and 63 and 131 in Monticello. The average concentration of radon 222 found at each station in the four study sites is given in table 1. (Each sample result is in appendix II.)

The data shown in table 1 covers the following dates at each of the four study areas:

Grand Junction	June 6, 1967 to August 20, 1968
Salt Lake City	October 27, 1967 to October 9, 1968
Monticello	August 8, 1967 to July 29, 1968
Durango	August 3, 1967 to July 30, 1968

As stated earlier, each of the 57 sampling stations was resampled at 3-week intervals throughout the study.

Table 2 presents an overall summary of the onpile and offpile radon concentrations for the four study sites. Four of the offpile stations in Grand Junction, and one of the offpile stations in Durango, have been shown separately from the other offpile stations. The reasons for this are explained below. The averages are also shown in figures 1 to 4 with the corresponding sampling location at each of the four study areas. For the sake of clarity, only the principal city and residential areas have been shown. In figure 1, the average of the onpile stations is shown for clarity instead of the individual averages.

DISCUSSION

The conclusions and trends are presented below for each of the four study areas:

GRAND JUNCTION

It is apparent when examining these data that there are three distinct groups: (1) onpile stations; (2) near-pile stations in the prevailing wind patterns; and (3) all other stations.

Table 1. Average concentrations of radon 222 found at the four study areas

Station and location	Number of samples	Concentration of radon 222 (pCi/liter)		
		Average	Standard deviation	Range
Grand Junction, Colo.				
11[a]	17	11	6.7	3.3 - 28
12[a]	17	4.7	1.7	2.2 - 7.1
13[a]	17	9.0	3.6	4.6 - 21
14[a]	17	5.7	2.4	1.1 - 9.7
15[a]	17	8.7	3.9	3.5 - 16
16	17	1.1	.53	.50 - 2.6
21	16	.77	.35	.37 - 1.8
22	17	1.3	.67	.53 - 2.3
23	17	3.4	3.0	.60 - 13
24	17	.78	.45	.31 - 2.2
25	17	.84	.45	.28 - 1.9
26	17	.82	.50	.30 - 2.2
31	16	1.1	.88	.42 - 3.3
32	16	.75	.41	.19 - 1.8
33	17	1.8	1.1	.50 - 4.5
34	15	.84	.39	.46 - 2.2
35	17	.88	.51	.32 - 2.1
36	17	.88	.41	.33 - 1.9
41	16	.69	.30	.13 - 1.2
42	16	.70	.27	.27 - 1.1
43	15	.78	.48	.17 - 1.9
44	16	1.1	.93	.48 - 4.4
45	16	.82	.33	.40 - 1.6
46	15	.74	.43	.35 - 2.1
47	10	.79	.48	.29 - 1.9

[a]Onpile stations.

Table 1. Average concentrations of radon 222 found at the four study areas (continued)

Station and location	Number of samples	Concentration of radon 222 (pCi/liter)		
		Average	Standard deviation	Range
Salt Lake City, Utah				
81[a]	16	10	6.4	1.6 - 22
82[b]	15	4.2	1.4	2.3 - 6.6
83	16	.43	.31	.09 - 1.3
84	15	.39	.24	.21 - 1.1
85	13	.68	.30	.23 - 1.4
86	13	.28	.14	.11 - .54
91	15	.44	.30	.15 - .99
92	14	.42	.24	.17 - .85
93	14	.24	.12	.06 - .55
94	17	.44	.26	.07 - .94
95	17	.29	.16	.13 - .60
96	16	.22	.12	.06 - .45
Monticello, Utah				
61[a]	17	4.1	2.0	.68 - 8.1
62[a]	15	2.4	1.2	.55 - 4.4
63[a]	15	4.5	3.1	.12 - 12
64[a]	16	3.1	1.8	.89 - 6.1
65	17	.52	.29	.18 - 1.3
66	16	.41	.17	.12 - .64
71	15	.34	.18	.10 - .72
72	17	.24	.13	.03 - .53
73	16	.29	.17	.06 - .59
74	17	.24	.13	.06 - .59
75	16	.31	.18	.14 - .87
76	17	.40	.20	.11 - .94
Durango, Colo.				
51[a]	16	19	7.2	3.8 - 34
52[a]	14	12	9.1	.48 - 32
53	15	.49	.17	.25 - .75
54	10	1,4	.67	.44 - 2.3
55	17	.52	.27	.11 - 1.3
56	14	.47	.17	.22 - .78
57	13	.59	.35	.17 - 1.2
58	13	.47	.34	.09 - 1.3

[a] Onpile stations.

[b] This station is not actually onpile, but adjacent to the pile at the sewage plant.

Table 2. Summary of onpile and offpile stations at the four study areas

Location	Number of stations	Number of samples	Concentration of radon 222 (pCi/liter) Average	Range
Grand Junction, Colo.				
Onpile	5	85	7.8	1.1 - 28.0
Near-pile[a]	4	68	1.9	.50 - 4.5
Other	16	252	.83	.13 - 4.4
Durango, Colo.				
Onpile	2	30	16.0	.48 - 34.0
Station 54	1	10	1.4	.44 - 2.3
Other	5	72	.51	.09 - 1.3
Monticello, Utah				
Onpile	4	63	3.5	.12 - 12
Offpile	8	131	.34	.03 - 1.3
Salt Lake City, Utah				
Onpile	1	16	10	1.6 - 22
Station 82	1	15	4.2	2.3 - 6.6
Offpile	10	150	.38	.06 - 1.4

[a]Near-pile stations were stations 16, 22, 23, and 33.

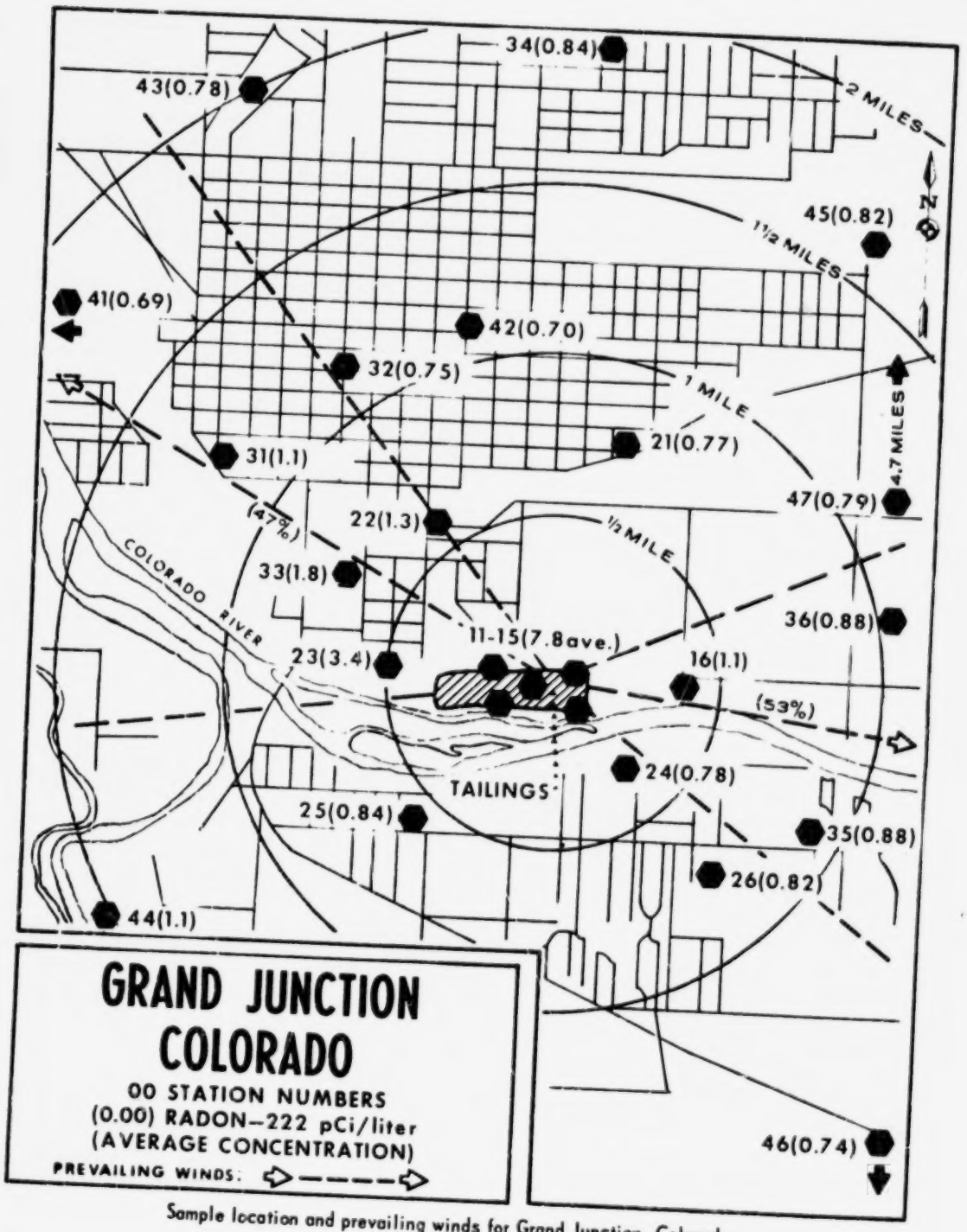
The wind patterns (shown as dotted lines on figure 1) represent conditions that occur about 80 percent of the time. The early daytime winds are from the southeast while the afternoon and evening winds are from the northwest. The shift is about equally divided in the two directions; about 53 percent of the time from the northwest and 47 percent of the time from the southeast.

It is interesting to note that station 11, which has the highest average radon 222 concentration, is positioned at the northwest corner of the main tailings pile at the foot of a 25-foot bluff in the prevailing wind envelope for the nocturnal inversion conditions. This station can be expected to intercept the drainage of radon from the pile down the slope during periods of highest concentration. In contrast, the lowest value of the onpile stations is obtained at station 12, which is almost in the geometric center of the pile. The pile is slightly conical with station 12 near the apex. Apparently, except under conditions of strong vertical mixing, the radon drains down the slope and away from the sampler, minimizing the concentration available at a height of 3 feet where the inlet is located.

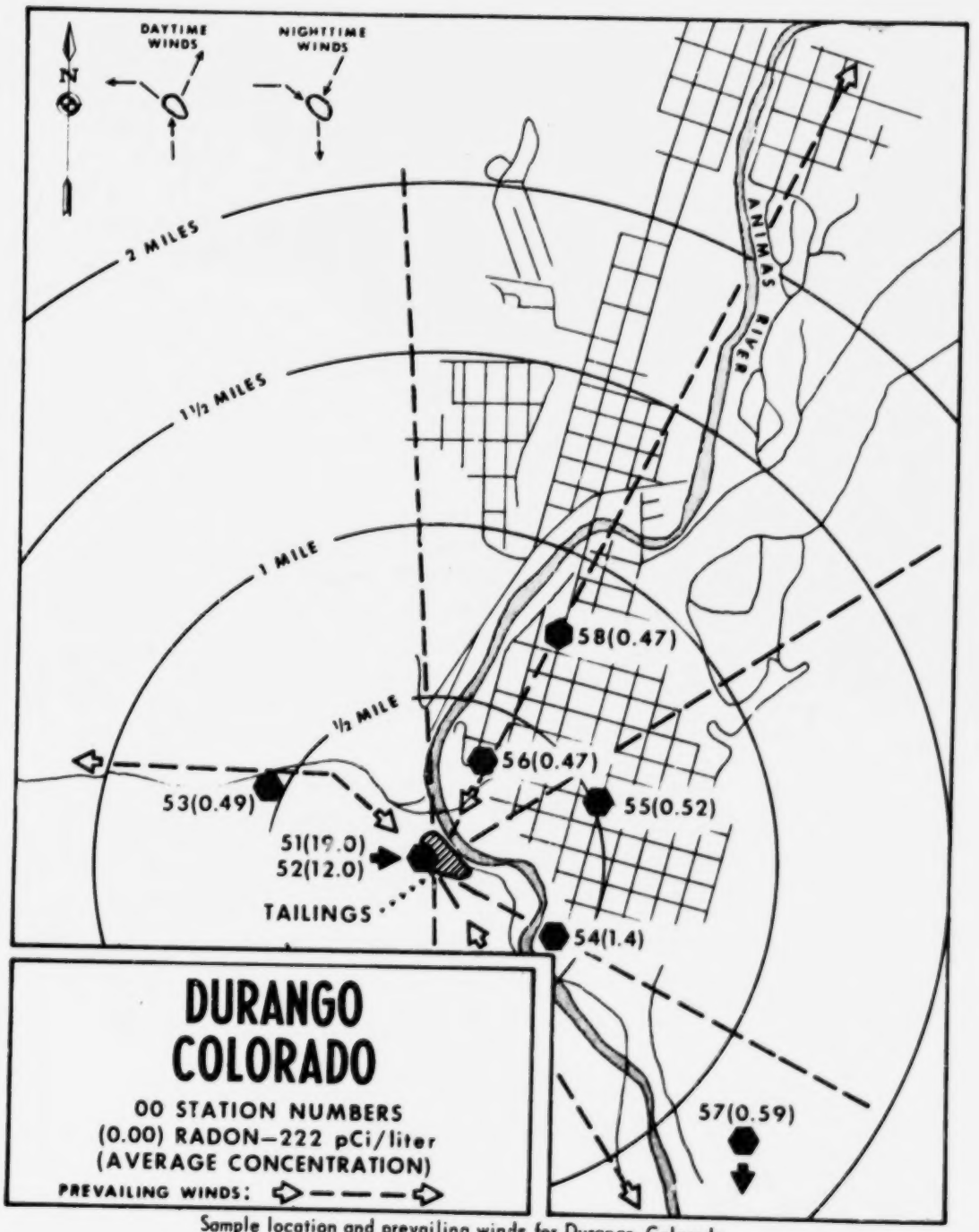
As previously stated, it was considered valid to consider stations 16, 22, 23, and 33 as a separate group from the other offpile stations. There are several reasons for this: (1) they are all about one-half mile from the pile; (2) they are in the predominant wind envelopes; (3) the area is characteristically industrial; and (4) they are all on the mill side of the river. In addition, standard t-test and analysis of variance comparisons of station averages clearly showed that stations 23 and 33 were significantly different from the other offpile station averages. Stations 16 and 22, while exhibiting higher averages than offpile stations, were not determined to be significantly higher, but were considered to fall into the same "population group" as stations 23 and 33.

Station 24 was not included in this group because, while it is less than one-half mile from the pile and is in the predominant wind envelope, it is situated across the river close to the edge of a mesa about 80 feet higher than stations 16, 22, 23, and 33. Station 23 (fig. 1) is the closest offpile station and has the highest average.

The remaining 16 offpile stations were considered as a third group of stations. For these stations, the individual station averages were compared utilizing standard t-test and analysis of variance comparisons of the averages. The results of these statistical techniques showed that none of the individual station averages could be considered significantly different (at the 95 percent confidence level) from each other and, therefore, would represent data from the same "population group."



Sample location and prevailing winds for Grand Junction, Colorado
Figure 1



Sample location and prevailing winds for Durango, Colorado
Figure 2

The above conclusion is quite significant when comparing station 47 with the others. Previous to 1966 a quantity of tailings material was distributed widely throughout the Grand Junction community. These tailings were used as fill material, subgrade material under buildings, and other uses. It was felt that the tailings pile at the mill might not represent a single point source of radon release to the general environment, and that the distributed tailings might influence the radon concentrations at outlying stations. To investigate this possible variable, a station was set up at a considerable distance from the main tailings pile in an area where it was known that no tailings had been distributed; station 47 was located at a distance approximately 5 miles north of the main tailings pile. This station was placed in operation in early February 1968. As can be seen from table 1, the average radon concentration at station 47 for the study period was 0.79 pCi/liter. This average is not significantly different from the overall average of 0.83 pCi/liter for the offpile stations. It is thus concluded that the radon concentrations at station 47 are indicative of background levels in the Grand Junction area. In comparing this station's average with the other offpile stations (exclusive of stations 16, 22, 23, and 33) it is reasonable to conclude that the main tailings pile is not appreciably increasing the general atmospheric radon concentration in Grand Junction. The true influence of the distributed tailings on the general atmospheric radon levels is not known.

No definitive quantitative correlation of radon concentrations with distance from the tailings pile could be obtained. Because of this lack of correlation, and because a known background station indicates a value of at least 0.79 pCi/liter, it appears reasonable to consider that the background concentration of atmospheric radon 222 for Grand Junction as a whole is 0.8 pCi/liter. If this figure is subtracted from the other values, no offpile stations are above the value of 3 pCi/liter permitted by Federal regulations (3) for uncontrolled areas. Stations 23 and 33 are at, or slightly above, the screening level of 1.0 pCi/liter recommended for this study. All other station averages are well below 3 pCi/liter.

DURANGO

The onpile station averages at Durango are considerably higher than the other study locations. The most likely reason for this is the physical location of the sampling sites. Because of the very steep side slopes of the tailings pile, as

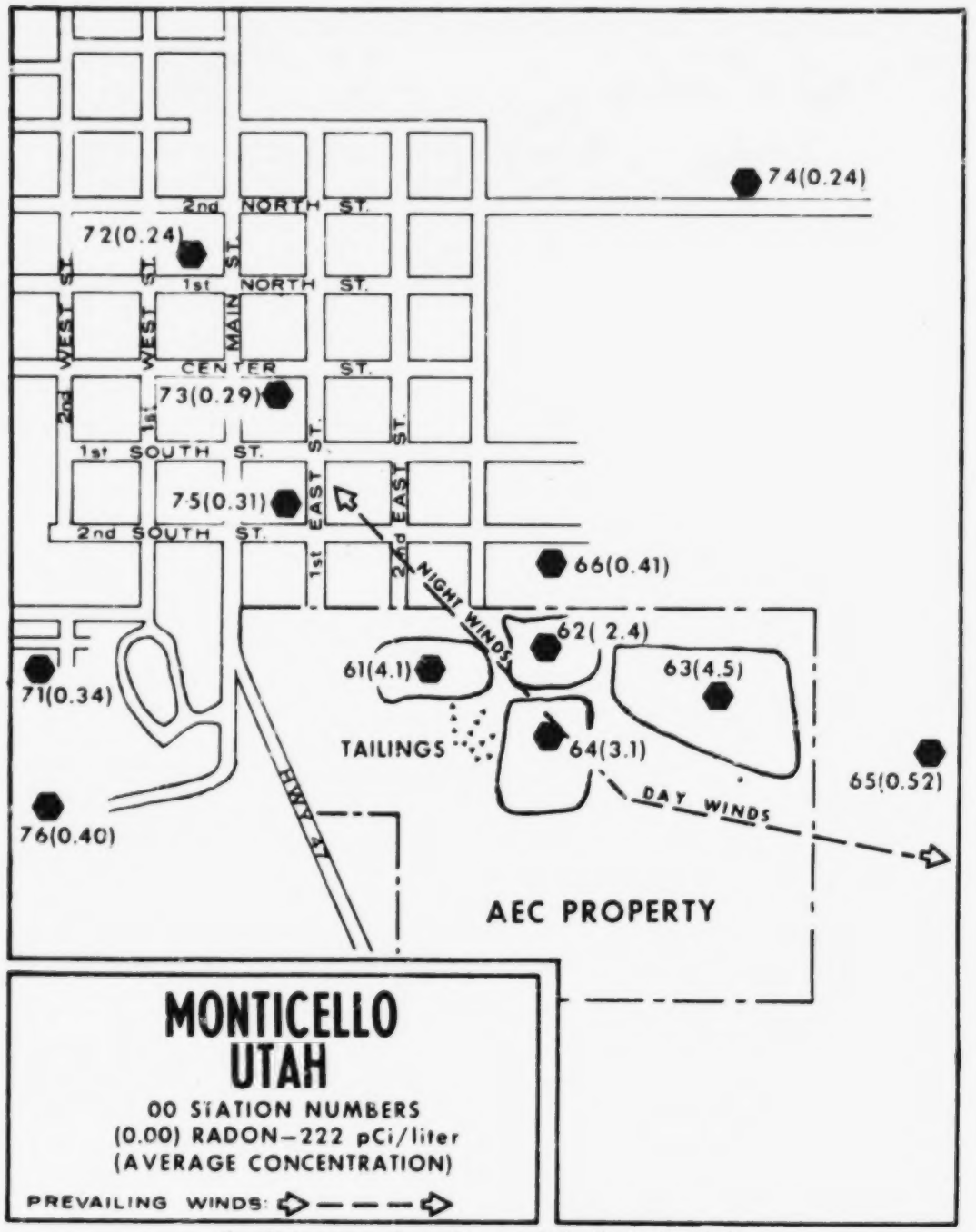
well as its location against the side of a mountain, it was not convenient to locate the sampling sites directly on top of the pile; instead, the samplers were located on tailings material at the base of the tailings dike. It is probable that the radon diffusing out of the entire side slope of the pile will be carried by air movement directly down to the sampler at the base of the pile under almost all meteorological conditions, thereby ensuring a high concentration of radon at all times.

The wind patterns at Durango are shown as dotted envelopes in figure 2. The daytime winds are from the southeast and split toward the northeast and west at about the mill area. The nighttime winds are the reverse.

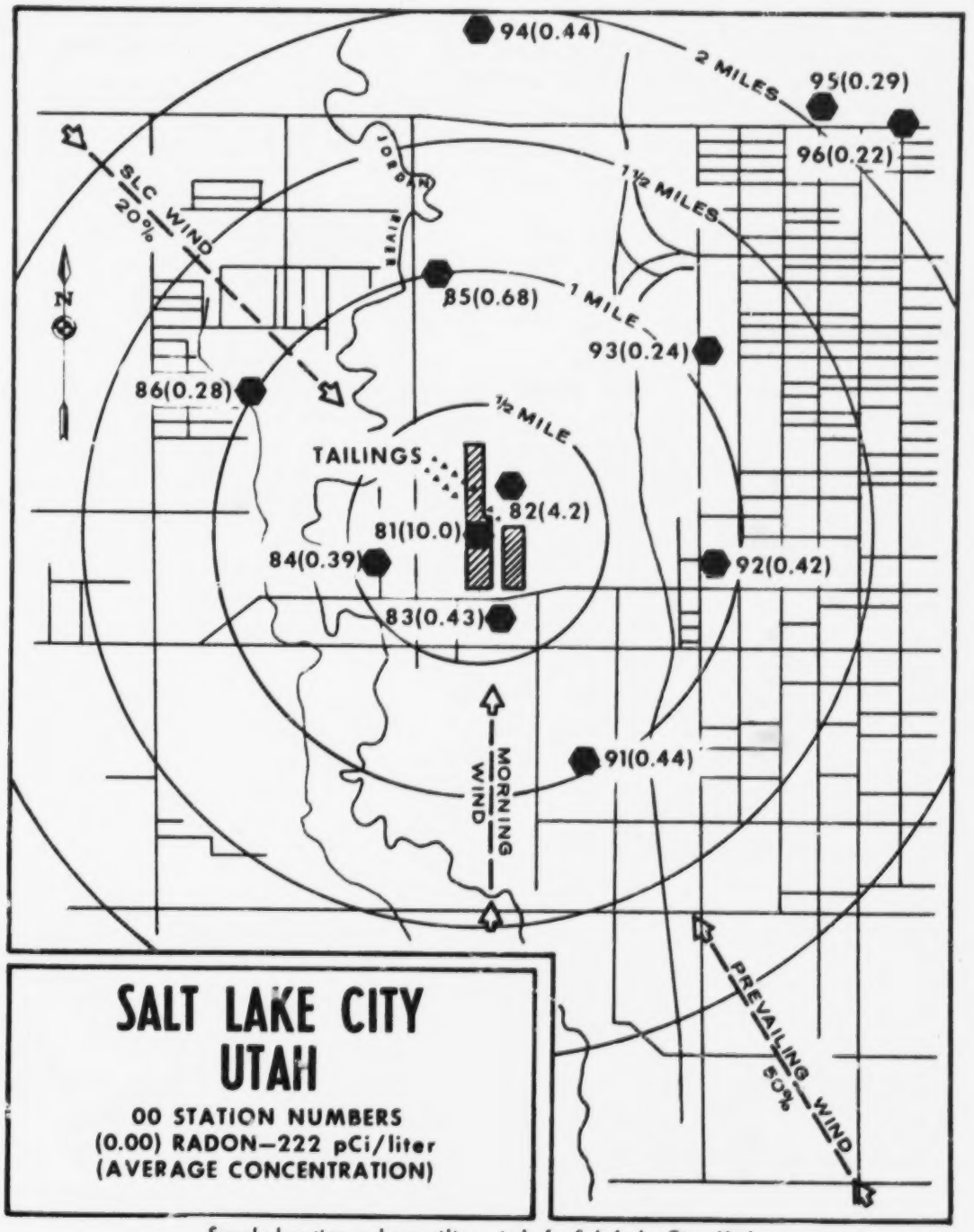
Standard t-test and analysis of variance comparisons of the averages of stations 53 through 58 showed that station 54 was significantly higher than the others, and that all other stations were not significantly different from each other. Station 54 is listed separately from the other offpile stations in table 2. Station 54, one-quarter mile southeast of the pile inside the wind envelope for the nocturnal inversion conditions, is across the river at the sewage-treatment plant. It is reasonable to conclude that the average of all offpile stations with the exception of station 54 represents the natural background levels for this area. This average (table 2) is 0.51 pCi/liter. If this figure is subtracted from the average at station 54, the resulting net average is 0.89 pCi/liter or less than the screening level of 1 pCi/liter. As at Grand Junction, no correlation of radon concentration with distance could be made from the Durango data.

MONTICELLO

During its operational period, the Monticello mill was owned by the U.S. Atomic Energy Commission. Following termination of operation, the tailing areas were leveled and covered with earth and planted with a grass cover. This stabilization was completed in 1962. One objective of this study was to determine the effect of stabilization and covering on emanation of radon gas from piles. For this reason, Monticello was selected as one of the study locations. There are four distinct tailings areas at Monticello (fig. 3). It was deemed desirable to locate a sampling station on each of these areas. Other sampling locations were selected taking into consideration prevailing wind patterns.



Sample location and prevailing winds for Monticello, Utah
Figure 3



Sample location and prevailing winds for Salt Lake City, Utah
Figure 4

Standard t-test and analysis of variance comparisons of averages were made on all the offpile stations. The results showed that none of the offpile station averages was significantly different from the others. This indicates that the tailings do not significantly affect the environmental radon levels away from the tailings area. The average of all offpile stations (0.34 pCi/liter) can be considered to represent background for the Monticello area. If this value is subtracted from the other results, even the onpile net average concentration of 3.2 pCi/liter is only slightly above the permitted guideline (3) for continuous exposure in uncontrolled areas.

Salt Lake City

Station 81 is located directly on tailings and station 82 is closely adjacent at the sewage-treatment plant (fig. 4). Individual occupancy is only 40 hours a week at the sewage-treatment plant. The averages for the offpile stations (exclusive of station 82) were compared using a standard t-test and an analysis of variance. There was no significant difference among stations.

As in Monticello, the offpile station average of 0.38 pCi/liter was considered to be the most reasonable estimate of the natural background concentration in Salt Lake City. Subtracting the background gives values for the onpile station and the sewage-treatment plant of about 3 times and 1-1/3 times, respectively, the regulatory guideline for continuous exposure in uncontrolled areas.

Intercity Comparisons

Because of the significant differences in the distances and orientation of samplers with respect to the piles, differences in meteorological variables, and the shape, size, and condition of the piles themselves, it is extremely difficult to make comparisons among cities from these data. There is no evidence of a significant contribution of radon to any of the cities beyond one-half mile from the piles. Even comparison of the piles is imprudent. Estimates of the radium 226 content of the tailings material show the concentrations to be almost identical for all four cities at about 900 pCi/gram;

consequently, concentrations of radon 222 above these tailings might also be expected to be quite similar. The data in table 2 show this to be true for the piles at Grand Junction and Salt Lake City. It is tempting to postulate that the concentration at Durango would also have been similar if it had been possible to locate the sampling station on top of the pile, and if the pile were essentially flat as were the other two.

Effect of Stabilization

Any type of covering placed on tailings material will result in some decrease in the radon emanating from the tailings if for no other reason than the additional radiological decay resulting while the radon is diffusing through the covering. Based on the similar specific activity of the tailings at the four study locations, and the actual onpile radon concentrations obtained thus far, it is tempting to conclude that the type of stabilization carried out at Monticello has been effective in reducing the radon concentration over the tailings by approximately 50 percent; however, this is a tenuous conclusion. The quantity of tailings per unit area of land varies among the four sites in this study by a factor of four. Variations in vertical mixing, because of meteorological conditions, are undoubtedly more important in determining radon concentrations above the piles than small variations in specific activity or distribution of tailings.

Comparison of the offpile data among the four study areas indicates that the background radon concentrations in Durango, Monticello, and Salt Lake City are quite similar and are about one-half of the concentration in Grand Junction. It is apparent that the general Grand Junction area has a higher radon 222 background than the other locations studied.

Radiation Exposure Interpretation

The guide for radon 222 assumes the parent in complete equilibrium with its short-lived daughters, which actually contribute about 95 percent of the total dose. These conditions would prevail directly over tailings only under completely stagnant weather conditions or at considerable distances from the pile. With a 10-mph wind, the composition of air at the 0.5-mile arc would correspond to the so-called

"3-min air;" that is, air aged sufficiently to build up 50 percent of the equilibrium activity of 3.05-min polonium 218 and little else. The actual dose received, therefore, will generally be far less than that inferred from the concentration of radon 222 alone. At distances more remote than one-half mile, the daughters might more nearly approach equilibrium conditions, but the total concentrations will have been so diluted as to be essentially negligible.

Thermoluminescent Dosimeter Results

During the latter part of this study it was considered desirable to obtain information on external radiation exposure at a number of the radon sampling stations. Thermoluminescent dosimeters (TLD's) were placed at each of the four study sites.

The TLD's used were of the CaF_2:Mn type. They were shipped from the laboratory and placed at a number of stations. At each station three TLD's were placed at the same height above the ground as the air intakes of the radon samplers. They were exposed for 30 days and returned for readout. The dates of exposure were June 17 to July 17, 1968.

Those stations situated directly over tailings (with the exception of Monticello) range from 0.2 to 1.1 mR/hr. This range is in good agreement with values found during previous environmental surveys at the Tuba City, Ariz. and Mexican Hat, Utah tailings areas. The Monticello site (covered pile) shows exposure rates of 0.03 and 0.06 mR/hr on the pile. These values agree with those presented by Paas (4). All other stations show normal background levels of exposure. The difference between Grand Junction offpile stations (0.02 mR/hr) and the offpile stations at the other locations (0.01 mR/hr) is insignificant.

Table 3. Thermoluminescent dosimeter results

Location	Station	Net average exposure rate (mR/hour)
Grand Junction, Colo.	11[a]	0.2
	12[a]	.4
	16	.02
	33	.02
	42	.02
	47	.02
Durango, Colo.	51[a]	.4
	55	.02
	58	.01
Monticello, Utah	63[a]	.03
	64[a]	.06
	72	.01
	74	.01
Salt Lake City, Utah	81[a]	1.1
	85	.01
	86	.01
	91	.01
	96	.01

[a]Onpile stations.

SUMMARY AND CONCLUSIONS

The results of a joint PHS – AEC yearlong study to evaluate the public health aspects of atmospheric radon 222 concentrations in the vicinity of uranium mill tailings piles are presented. Samples were collected from 13 onpile and 44 offpile stations in the four study cities of Grand Junction and Durango, Colo., and Monticello and Salt Lake City, Utah. The tailings pile at Monticello has been covered and stabilized; the other three are uncovered and unstabilized. The side slopes of the pile at Grand Junction are partially stabilized with a grass cover.

On the basis of the data gathered at the four study sites, it is possible to reach the following conclusions:

1. The background radon 222 concentration at Grand Junction averages 0.8 pCi/liter and is approximately double the background concentrations at the other three study sites.
2. The tailings at the four study sites are not significantly affecting the atmospheric radon concentrations beyond a distance of one-half mile in the prevailing wind directions.
3. Of the 44 offpile stations, exclusive of station 82 at Salt Lake City, only two exhibited an average radon concentration (above background) equal to or higher than the 1 pCi/liter screening value adopted for this study.
4. The measured concentrations of radon over the stabilized tailings at Monticello are less than those over the other tailings in this study. Determination of the precise effect of stabilization would require sampling before and after stabilization at a specific site.

The conclusions are:

1. A technique for taking integrated air samples for radon near uranium tailings piles has been developed, tested, and proven through use in the field.
2. Atmospheric concentrations of radon in areas near uranium tailings piles have been evaluated as an index to radiation exposure of the population. The results indicate no significant radiation exposure to the public from this source.
3. Stabilization and covering of uranium tailings piles in theory should reduce the emanation of radon from the piles; however, the evidence for this is not conclusive from data obtained during this study.
4. Development of point recommendations to control public exposure to radon from uranium tailings piles is not necessary, as no significant public exposure was indicated by the results of the study.

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APPENDIX I

AN INTEGRATING AIR SAMPLER FOR DETERMINATION OF RADON 222

During the processing of uranium ores for the recovery of uranium, the insoluble portion of the ore remaining after the uranium has been leached out is stored in huge piles adjacent to the mill. Since most of the ores processed are relatively low grade, averaging only about 0.25 percent U_3O_8, the quantity of tailings generated is 98 to 99 percent of the quantity of ore processed. By the end of 1970, the projected total tailings will amount to approximately 90-million tons contained in 35 separate piles. The radioactive daughters of uranium are not leached out of the ore significantly and remain almost completely in the tailings material. The most toxic of these waste products are 80,000-year thorium 230, 1,600-year radium 226, 22-year lead 210, and 138-day polonium 210, the first three of which are bone-seekers, and all are either alpha emitters or give rise to alpha emitters. Since the radioactivity of the tailings material averages about 700 pCi/gram for each radionuclide in the uranium chain, the total inventory amounts to about 58,000 curies of each radionuclide or the equivalent of over 125 pounds of radium 226.

Although the total inventory of radioactive nuclides in the tailings material is impressive, the hazard from particulate materials is not very great. The sands are quite coarse and settle back to the ground within a short distance, and most of the active piles are kept sprinkled to minimize blowing. The material has such a low specific activity that the small quantity that remains airborne for significant distances is thought by many experts to represent more of a hazard from pneumoconiosis or a civic nuisance than any real threat from the standpoint of internal dose; in fact, air dust surveys show concentrations of less than a few percent of the maximum permissible concentration (MPC) for continuous exposure to the entire population at distances in excess of perhaps one-half mile from the pile.

Recently, attention has been directed toward the possibility of a larger dose to the population in the vicinity of the tailings piles from radon and its daughters than from the particulates. Unlike any of the other uranium daughters, radon, the immediate decay produce of radium 226, is a gas that diffuses out of the solid tailings into the air where it decays further to produce other radioactive products; 3.05-minute polonium 218, 26.8-minute lead 214, 19.7-minute bismuth 214, and 164-μsecond polonium 214. These short-lived radon daughters are particulate and are filtered out in the lungs during normal respiration. When in equilibrium with their parent, the daughters are responsible for approximately 95 percent of the total dose resulting from the presence of radon. Because of the large mass of tailings materials, its associated radium 226 content, and the ability of radon to diffuse out of the solid pile, the radiological dose to the lungs from the gaseous radon and its particulate daughters might actually exceed that from the longer-lived nuclides in the tailings material itself. Recent calculations (1) suggest that the dose is maximal to the segmental bronchi, with an annual dose of 13.8 rads resulting from a concentration of 10.1 pCi/liter. A program was initiated to evaluate the radiological hazard to those in the vicinity of the mill tailing piles resulting from radon and its short-lived daughters.

In an exploratory survey to determine how great the hazard might be, 36 samples from four different cities were analyzed for radon 222 by a modification of a conventional method (2) involving absorption of the radon on activated carbon, elution at 500° C., and counting in a scintillation chamber (3). These preliminary samples were obtained by allowing an evacuated 16-liter stainless steel tank to fill to atmospheric pressure spontaneously. Samples were taken directly both under convective conditions in the afternoon and under the inversion conditions occurring in the early morning hours.

The highest value of 38.3 pCi/liter was obtained directly over tailings under nocturnal inversion conditions; the value dropped to 5.6 pCi/liter for the afternoon sample at the same location. The second highest value of 24.7 pCi/liter was taken near one edge of the tailings pile, but definitely off the property in an unrestricted area. Five other samples taken within about one-half mile from the respective piles were between 1/3 and 1 times the MPC of 3 pCi/liter permitted by regulation for continuous exposure to the general public in uncontrolled areas (4). The remaining samples from residential areas were not significantly different from background samples taken at approximately the same time several miles distant from tailings areas.

These preliminary results suggest that radon concentrations above the regulatory values for unrestricted areas can be obtained at almost any time directly over tailings and occasionally in uncontrolled areas, particularly at short distances downwind from the pile during nocturnal inversions. Although there appeared no need for alarm, the data clearly demonstrate the need for more sophisticated measurements to determine the average yearly concentrations of radon issuing from the piles and in unrestricted areas. The actual radiological hazard from radon emitted from tailings piles is difficult to assess. Exhalation of radon from the ground varies markedly with time and is particularly dependent on the condition of the surface and the prevailing meteorological conditions (5-11). Hosler (5) refers to recent measurements that have shown that ". . . variations of radon exhalation rates from a given type of bed rock or soil surface are small relative to the variations in air concentrations that can be attributed to vertical mixing." Normally, the radon content in the air near the ground increases during the nocturnal inversion period and decreases during the daytime convective period when atmospheric dilution is at a maximum and can be expected to change significantly by the hour.

Federal regulations permit the radiation dose received from licensed facilities by the population in uncontrolled areas to be averaged over a period of 1 year (4). A reasonable sampling program should logically cover at least a 1-year period to sample radon under all meteorological conditions prevailing during the same time period over which the radiation dose is averaged. If separate samples were taken by conventional techniques employing evacuated flasks that literally sample for only a few seconds at a time, such a program would become almost prohibitively expensive in terms of numbers of samples and analyses required if many sampling stations were involved. In contrast, if the sample itself could be averaged by being collected continuously at a constant flow rate for several hours at a time, a single analysis would give an average value for the entire period sampled. Such integrated samples would obviously permit air to be sampled for a greater fraction of the total time available for a given cost, and permit a more realistic evaluation of the radiation dose to be made.

A sampling period of 48 hours was selected as being about the longest time that could be used without introducing a large uncertainty due to radioactive decay of the 3.823-day radon 222 during the sample collection period. If the activity were calculated to the midpoint of the collection period, the error from this cause could not exceed about 15 percent, if all the radon were collected during the first or last 2 hours (a most unlikely occurrence). With the variations in radon concentra-

tions normally encountered, the error is not expected to exceed about 5 percent. Sampling for 2 diurnal cycles should smooth out the marked diurnal fluctuations and give a good average value for the entire period. This single integrated sample should be far superior to that obtained from many spot samples taken over the same time period. Sampling will be repeated at each location every 3 weeks to cover 10 percent of the total time available for exposure and to sample every calendar month, every season, and every usual meteorological condition occurring within 1 calendar year with only 17 samples per station.

To minimize transportation problems, the sample collected should be no larger than that necessary for analysis. Only 6 liters of air is required to detect activities higher than about 0.01 pCi/liter in a 1-hour count. Allowing for duplication of analyses and radiological decay during shipment from field location to the laboratory, approximately 30 liters of air should be adequate even for cross-checking between laboratories. If the sampling period is to cover 48 hours, the flow rate must not exceed 10 ml/min. The present investigation was initiated to develop equipment for collecting air at a reasonably constant low flow rate, in outdoor locations under all kinds of weather conditions and at locations frequently remote from a source of electric power.

Available equipment capable of doing the job was too expensive to permit large numbers of stations to be sampled simultaneously and meet the desired schedules. Initial attempts to assemble adequate equipment from commercially available parts were unsuccessful. A conventional piston-type compressor was used to pump filtered air through a flowmeter into an evacuated 2-liter stainless steel tank in the hope that the pump would be sufficiently powerful to fill the tank to several atmospheres pressure without decreasing the flow rate. When the pump was choked down from its rated capacity of 1.5 cfm to the required rate of only 10 ml/min, nearly 10 times as much air slipped past the piston as came in through the inlet. It is absolutely necessary to the success of this procedure that all air entering the sample container be filtered free of any dust containing radium 226 that will contribute additional radon during the long times involved from sample collection to final analysis and interfere seriously with proper decay corrections. A similar pump, having a rubber diaphragm to prevent leakage, could not maintain a constant flow as the rigid-walled container filled with gas. From these preliminary attempts, it seemed evident that (1) a pump would have to be used whose nominal capacity did not exceed greatly the sampling rate desired, and (2) a collapsible bag would have to be employed as a sample container to eliminate decreasing flow rate as sampling proceeded.

SAMPLING EQUIPMENT

PUMP

The pump finally used was a small 4-watt, 117-volt aquarium aerator called the Silent Giant (Model 120, Aquarium Pump Supply Inc., Prescott, Ariz.) that employs a cup and plunger compression chamber sealed by a flexible web and operated by an electromagnet. The pump also employs an efficient method of back-pressure compensation so that the flow rate is not affected significantly by conditions of air use or depth of water in the aquarium that is helpful in the present application. Under conditions of free flow, the pump delivers about 3 liters/min of air. With a needle valve restricting the flow from 0 to 125 ml/min, the pump builds up a pressure of about 6 psi.

As supplied commercially, the air inlet to the pump consists of several small holes in the interior can in which the pump mechanism is contained. To provide a single specific air inlet so that the incoming air can be filtered free of radium 226 and also to permit a tube to be run directly into the air stream to be sampled while the pump itself is protected inside a weather shelter, the interior can was reencased in a plastic housing made conveniently from 3.5-inch o.d. tubing, 4 inches long and 1/8 inch thick. Both ends were sealed with flat plates one-half inch thick, one end of which had been previously drilled and tapped to provide the necessary air inlet and outlet and electrical connections. When sampling at locations remote from a source of electric power, the pump can be operated from a 12-volt storage battery through a small power inverter (Model 50-103, Newark Electronics Corp., Chicago, Ill.) built for use in operating an electric shaver from an automobile storage battery.

FLOW REGULATOR

The first samplers used a small variable-area type flowmeter and a fairly coarse needle valve to control and indicate the air flow obtained. Even with fairly expensive models, the flowmeter itself appeared to contribute considerably to the instability of the air flow because of sticking floats, and so forth; consequently, the flowmeter and needle valve assembly were replaced by a precision extra-low-flow needle valve with a direct reading digital handle (Model 8502, Brooks Instrument Division, Hatfield, Pa.). Under the pressure of 6 psi supplied by the aquarium pump, a flow rate of about 125 ml/min is obtained with the valve wide open. The valve requires 15 turns from fully open to fully closed and can

be read to about one-twentieth of a turn. The flow rate can be quickly and easily calibrated by water displacement after which the same volume can be reproduced to within ± 1 percent by resetting the digital indicator.

SAMPLE CONTAINER

A collapsible container is necessary for use with the present low-volume pump to prevent significant changes in flow rate because of changing back pressure as the sample is collected. It is well-known that rubber, polyethylene, and many other kinds of plastics are extremely permeable to radon gas; in addition, natural rubber generally contains sufficient radium 222 to interfere seriously with the determination of radon. Bags made of Mylar have been used for years as meteorological balloons in weather science and are known to be capable of flying long distances without losing significant amounts of various gases such as oxygen, nitrogen, helium, and so forth. The present investigation shows that the same material is perhaps the best presently available for retention of radon.

The bags used were fabricated from a double layer of 3/4-mil Mylar laminated together to eliminate pin holes (GT-21, G. T. Schjeldahl Company, Northfield, Minn.). To make the bags, a strip of the laminated material of the size desired is folded over, and the side and both ends are sealed by inserting a strip of sealing tape (GT-400) between the two faces and ironing the tape area with a hand sealing iron at approximately 350° F. until the milky appearance disappears from the tape, indicating that a good bond has been achieved. A dill valve available from bicycle or hardware stores, is placed in the face of the bag prior to sealing. The bags used in the present study have inside dimensions of 17-3/4 inches by 31-3/4 inches with the bag lying flat, and hold approximately 40 liters when filled completely. The bags are made somewhat larger than the volume to be contained to provide room for expansion at temperatures and pressures other than those at which the sample is collected (mountain passes, aircraft, and so forth).

The complete sampling equipment (figure 1) is connected to the small electric shaver inverter and storage battery for use in locations that are remote from a source of electric power. For sampling in remote or difficult-to-reach locations where weight and bulk must be kept to a minimum, such as in a uranium mine, the small 10-ampere-hour motorcycle battery provides sufficient capacity for an 8-hour integration over a shift. For sampling in remote areas above ground, a regular automobile storage battery of about 70-ampere-

FIG. 1. EQUIPMENT USED FOR TAKING INTEGRATED AIR SAMPLES FOR DETERMINATION OF RADON 222

hour capacity is necessary for a 48-hour sample integration. When 115-volt power is available, the electric plug is simply removed from the inverter shown and plugged into the source of a.c. power.

In operation, the entire equipment shown in figure 1 is placed in a weather shelter, and the piece of gum rubber tubing shown on the right is allowed to extend out of one end into the airstream to be sampled. A small funnel is inserted in the end of the tubing to prevent rain from being drawn in and saturating the filter, which would cause a marked decrease or complete stoppage of the airflow. The air is then drawn through a double 1-inch filter (in the conical holder) consisting of a glass-fiber roughing filter, followed by a membrane filter (GS-6 Gelman Instrument Company, Ann Arbor, Mich.) into the plastic case. The pump then draws the air through holes in the bottom of the can and expels it through the coiled tube, the needle valve, and into the Mylar bag. In actual use, the Mylar bag is contained in a cardboard box, 10.5 inches by 12 inches by 30 inches, inside the weather shelter to protect the bag from abrasion, air motion, and so forth, and to serve as a container in which to ship the gas sample back to the laboratory. Current cost of the equipment shown is about $55 for the a.c.-operated system, about $80 for the battery-operated system, and about $6 each for the Mylar bags.

PERFORMANCE

The operating characteristics of the pump and needle valve were determined by measuring the volume of water displaced from an inverted 10-ml graduated cylinder in 60 seconds under various conditions. A flow rate of 9.6 ml/min could be reproduced to within 0.1 ml/min or about 1 percent by setting the indication handle back to the same number from either fully open or fully closed provided the final adjustment was always made from the same direction.

EFFECT OF VOLTAGE

At a flow rate of 9.6 ml/min, changing the voltage from 135 to 105 volts changed the flow rate by less than about 1 percent. The flow rate drops to about 50 percent of its initial value at 90 volts and decreases rapidly at lower values. In fact, this same pump makes an excellent low-cost transfer pump for laboratory use, using a variable transformer to change the flow rate continuously and smoothly by changing the voltage in the lower voltage ranges. Care should be

taken so the voltage at the end of long runs of wiring required to reach remote locations is not permitted to drop so low that the flow rate becomes susceptible to normal voltage fluctuations. For the year-long program for which this equipment was developed, several thousand feet of No. 14 electric wire were used to reach most of the sampling stations on and around the mill tailings piles with a resultant voltage drop of less than 1 volt. Because of the very small power consumption of the pumps, longer runs of even smaller wire can be used to reach even more remote locations before the voltage drop becomes significant.

When battery operated, the pump and inverter together draw about 0.7 ampere which will use about one-half of the total capacity of a 10-ampere-hour motorcycle battery in 8 hours or of a 70-ampere-hour automobile battery in 48 hours. During an 8-hour period, the voltage of a new motorcycle battery dropped from 12.5 to 11.6 volts with less than about 2 percent change in flow rate. The automobile battery will undoubtedly act similarly, but either battery should be recharged before taking another sample.

EFFECT OF TEMPERATURE

The effect of temperature is more difficult to assess and interpret. Initially, the outlet from the pump was connected to the Mylar bag through a flowmeter. The entire assembly of pump, needle valve, and flowmeter were placed in a steel ammunition box only slightly larger than the assembly itself, the lid was closed tightly, and the flowmeter was read periodically through a single small opening in the box over a period of 2 days. The box was placed outdoors near the west wall of the laboratory building, so it would become cold during the night, warm up slowly during the forenoon hours when the box was in the shadow of the building, and finally become extremely hot during the afternoon when the hot summer sun shined directly on the box for several hours. Since the change in flow rate observed was less than 10 to 15 percent at most, no attempt was made to define temperatures quantitatively except to state that the steel box was so hot all afternoon that it could not be touched comfortably for longer than a few seconds at a time. At night, the air temperature was approximately 35° F. These temperature extremes are thought to be greater than those that need be tolerated if the pump assembly is placed in a ventilated weather shelter to protect it from the direct rays of the sun.

In another attempt to evaluate the effect of temperature, the flow rate was determined by water displacement while the needle valve and pump were alternately heated and cooled. After an initial adjustment of the flow rate to 9.6 ml/min

at 24° C., the flow rate decreased to 7.1 ml/min, or about 26 percent when the needle valve was heated with an infrared lamp hotter than could be touched comfortably for any significant period of time. When the needle valve was cooled with an aerosol spray used to cool electric circuits, the flow rate increased to 10.6 ml/min, or about 10 percent. Since the flow rate was measured by water displacement from a large tray of water at room temperature, the changes observed obviously reflect variations in mass transfer rather than volume. Both changes would undoubtedly have been smaller had the exit air remained more nearly at the temperature of the air being sampled. Since respiratory processes are more dependent on volume transfer than on mass transfer, it appears that the effect of temperature on the pump is not very different from its effect on the volumes breathed by humans. Again, no attempt was made to make a precise determination of a characteristic which is fundamentally imprecise in usage. It is unlikely that any reasonable temperature variation will introduce more than a 10 to 15 percent uncertainty between the volume sampled by the pump and that breathed by people.

Diffusion of Radon 222 through Mylar

The use of Mylar bags as containers for air samples for the determination of radon 222 depends on their ability to retain radon for the several days required for sampling, transportation to the laboratory, and analysis. To determine possible losses from diffusion, pin holes, faulty seams, or whatever cause under actual conditions of use, a bag was filled with approximately 30 liters of air containing sufficient radon 222 to give an initial counting rate of about 4×10^5 gamma counts per minute of daughter activity at equilibrium under the counting conditions employed. The bag of air was placed horizontally on a stretcher in a 9-foot cubical steel room used for whole-body counting and an 8-inch by 4-inch NaI(Tl) detector was placed over the center of the bag at a distance of about 12 inches. The bag was allowed to stand overnight to ensure ingrowth of the radon daughters to complete equilibrium. After rechecking the experimental set-up the following morning, the door to the vault was closed and sealed to prevent any traffic or air motion inside the vault that might change the orientation of the bag and thereby change the counting efficiency. A 1-minute count was made immediately and was repeated at approximately the same time on each successive day for the next 6 days during that time the door to the vault was never opened. An additional measurement was obtained on the 15th day that had not been

planned but was available, since the bag had not been moved from its original position; however, the vault had been opened after the last planned experimental point.

The decrease in activity obtained is shown in figure 2. The dashed line shows the expected decrease of 3.823-day radon 222 from the initial activity because of radiological decay alone. The solid curve was drawn through the six imtermediate points, which it fits better than anything that can be drawn to include the first and/or last points. A least-squares best fit of all the data gives an apparent half-life of 3.60 days, corresponding to a maximum loss of about 1 percent per day from all causes other than radiological decay. It is interesting to note that the first and last points obtained while the vault was open show no detectable loss in 15 days and are distinctly different statistically from the six intermediate points that were obtained while the vault was sealed. It is entirely possible that electrostatic attraction of the charged ions being measured to the nonconducting walls of the Mylar bag is biased in some unknown way by a stagnant environment. In any event, the slopes of the two groups of points are closer to each other than to the best fit of all the points, and loss of radon 222 must be less than 0.5 percent per day which is more than adequate for the intended use. Even if the losses increase somewhat when the bags are flexed, the overall loss should still be negligible compared to the other uncertainties present.

Although the diffusion of radon 222 through rubber and most plastics is known to be several orders of magnitude higher than with Mylar, short pieces of gum rubber tubing are used to make connections because of its ready availability and because its elasticity ensures that the connections are airtight. The quantity of rubber tubing used is so small and the residence time of the air in the tubing is so short that losses from this source are negligible. Measurements showed a loss of about 5 percent per hour from a 2-foot piece of the 1/8-inch tubing used. Since the bore volume is about 4 ml, loss from this source is only 0.03 percent for the entire 48-hour integration.

Lucite was used to reencase the pump mechanism because of its low cost and ease of fabrication. To determine if this plastic would cause significant loss of radon from a given sample and contaminate a subsequent one, the following experiment was performed. Thirty liters of air containing 40 pCi/liter of radon 222 present before and after pumping did not differ by more than could be expected from the experimental uncertainties involved. The pump was then flushed quickly with 1.5 liters of aged air in about 10 minutes with the valve wide open to determine how much of the residual gas in the void space could be removed in a short purge.

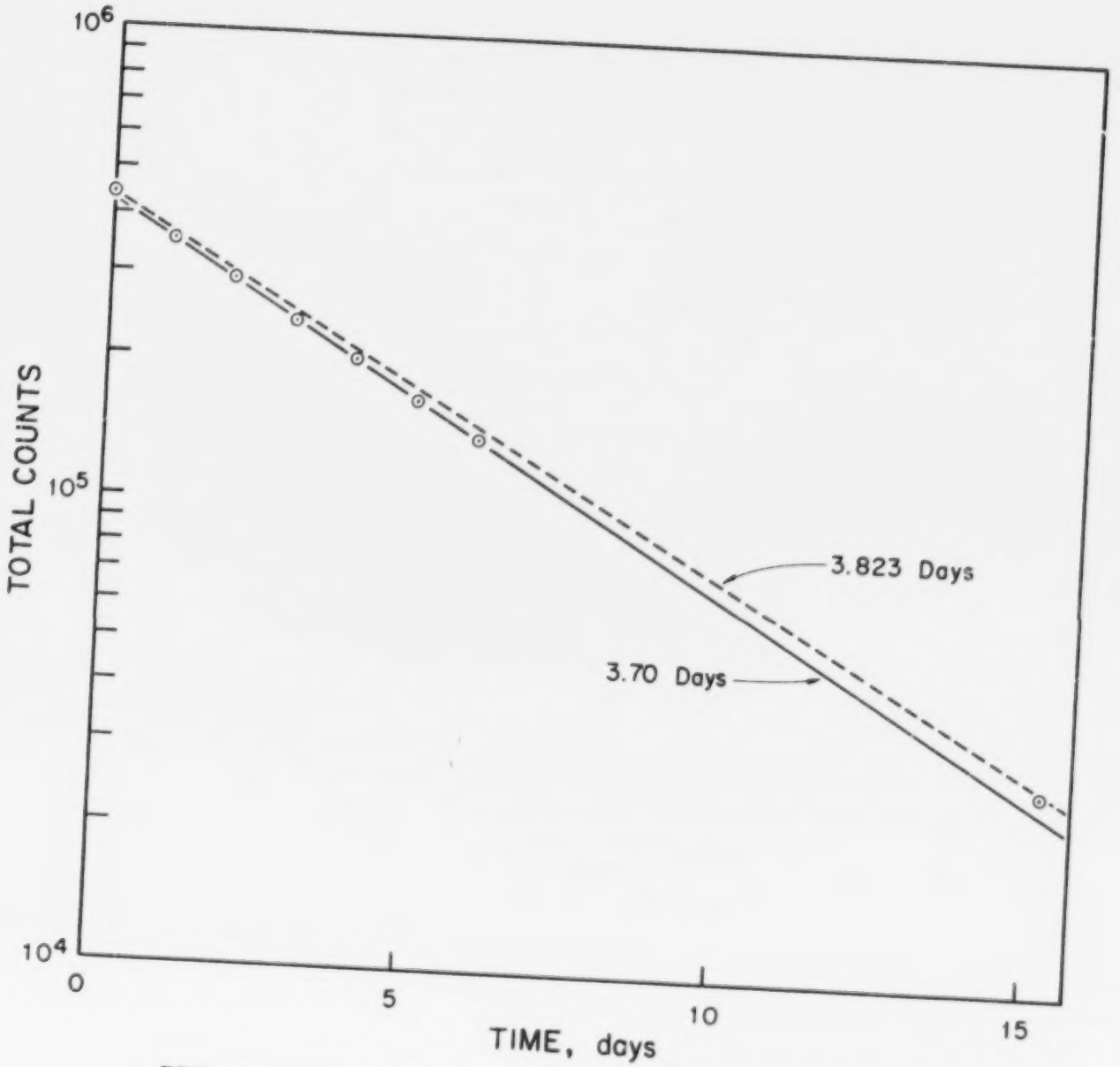

FIG. 2. DECAY OF RADON 222 CONTAINED IN A MYLAR BAG

Aged air was then pumped from a Mylar bag into an empty one at 10 ml/min for 48 hours to determine the quantity of radon that would diffuse back into a subsequent low-level sample during the lengthy collection period used in the field. The radon found in the purge and subsequent eluate was about 2.5 and 0.5 percent, respectively, of that taken in the original 30 liters of gas of which 1 percent is attributed to the free-volume space of about 300 ml. This contamination would increase the concentration of a subsequent 30-liter sample by a maximum of 1.2 pCi/liter, which can be reduced to 0.2 pCi/liter by a short purge with the valve wide open. In practice, the contamination will be even less because of decay between uses. Pumps used over tailings or in other areas of high radon concentrations should be purged before being used for sampling in low-level areas unless sufficient time is allowed for adequate radiological decay.

PRACTICAL APPLICATION

In cooperation with the U.S. Public Health Service and the health departments of the States of Colorado and Utah, a 1-year program involving 57 stations in four cities was instituted, based on the philosophy and equipment described above. The philosophy of employing 48-hour integrated samples to increase the reliability and decrease the cost of long-term measurements worked extremely well. Excellent coverage of the four study areas was obtained at minimum cost and results are clear, consistent, and singularly free of any significant anomalies. The sampling equipment performed almost as well in the field as it had in the laboratory, with a few exceptions. Of 18 complete samplers in use, five of the $15 pumps burned out and had to be replaced. This was probably due to the low flow rate that caused a much higher back pressure than that recommended by the manufacturer. A more frequent problem encountered was the occasional sticking of the needle valves that would not retract when the handle was turned to the open position. On prolonged use, a very small amount of corrosion occurs that tends to fix the needle in its existing position so that the spring-loaded return is insufficient to break it loose and open the valve. This problem is easily remedied by removing the needle and wiping it gently with a dry cloth before each 48-hour run.

The Mylar bags have held up very well on repeated use, with each bag being used an average of eight times without showing signs of significant deterioration. The infrequent breaks that develop where the Mylar has been creased sharply, and even an occasional tear, are easily and rapidly repaired

using sealing tape and a hand iron. The one really frustrating problem encountered in the entire program was the occasional obstinate refusal of some of the bags to fill up in the proper time even though it could be shown that air was entering the bag at the proper rate. The only reasonable explanation is the presence of pin holes in the bags or rubber tubing, minute leaks in the seams or valves, or a faulty connection to the valve. Obviously, it would not take much of an opening to permit the gas to bleed off as fast as it is collected, considering the very low rate involved. Some of the leaks are extremely difficult to find. If a bag is partially filled with air and then tested in the conventional manner by immersion in a large container of water, some of the leaks, particularly in the seams, will close off when pressure is applied and then open up again when the pressure is relaxed to the conditions under which the samples are collected. Leaks from very small pin holes, observed if covered with a very thin layer of water or soap solution, will stop if immersed under a greater depth of water; however, most leaks are readily detected by immersion in a vessel of water, and this method is used routinely to leak test all bags in the laboratory after the analysis has been completed and before they are returned to the field.

The same philosophy and sampling equipment will undoubtedly find many other applications in air pollution control.

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APPENDIX II

RADON SAMPLING RESULTS

All sample results for the program are shown in the following tables in chronological order for each sampling station. All values have been corrected for decay to the midpoint of the 48-hour collection period and corrected to the mean annual temperature and pressure for the site as follows: Grand Junction, 638 mm, 11° C.; Durango, 599 mm, 8° C.; Monticello, 587 mm, 8° C.; Salt Lake City, 654 mm, 11° C.

Results are shown under the appropriate contributing laboratory: "USAEC" denotes the Health Services Laboratory, Idaho Operations Office, U.S. Atomic Energy Commission, Idaho Falls, Idaho; "SWRHL" denotes the Southwestern Radiological Health Laboratory, Bureau of Radiological Health, U.S. Public Health Service, Las Vegas, Nev.

Whenever more than one determination was made on the same sample, the arithmetical average of the determinations was used in further calculations. The ± values give the standard deviation because of the counting statistics only.

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo.

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
11	1200	6-6-67	4.23 ± 0.21	4.72 ± 0.24	5.62	4.45
	1128	7-27-67	13.5 ± 0.2	12.9 ± 0.1		
	1215	9-6-67	20.9 ± 0.2	21.0 ± 0.2		
	1300	9-28-67	14.2 ± 0.1			
	1430	10-19-67	19.4 ± 0.2	19.1 ± 0.2		
	1010	11-14-67	27.5 ± 0.2			
	1450	12-9-67	4.30 ± 0.07		5.36	
	0935	12-27-67	7.3 ± 0.1			
	1010	1-23-68	10.2 ± 0.1			
	1000	2-13-68	6.42 ± 0.08			
	1000	3-5-68	7.7 ± 0.1			
	0945	3-26-68	6.67 ± 0.08			
	1000	4-16-68	3.34 ± 0.06			
	1015	5-7-68	12.3 ± 0.1			
	1015	5-28-68	12.0 ± 0.1			
	1320	6-27-68	12.9 ± 0.1			
	1000	8-20-68	8.40 ± 0.08			
12	0900	6-8-67	2.17 ± 0.11	2.21 ± 0.11	2.28	2.41
	1102	7-6-67	1.39 ± 0.05	1.28 ± 0.08	9.48	
	1115	9-26-67	5.71 ± 0.09			
	1027	10-17-67	5.19 ± 0.07	5.13 ± 0.07	5.15	
	1000	11-7-67	4.7 ± 0.1			
	1420	11-30-67	6.0 ± 0.3			
	1330	12-21-67	2.40 ± 0.07			
	1355	1-18-68	3.4 ± 0.1			
	1330	2-8-68	7.0 ± 0.1			
	1330	2-29-68	4.51 ± 0.07			
	1330	3-21-68	4.62 ± 0.07		4.78	
	1325	4-11-68	7.35 ± 0.09			
	1345	5-2-68	4.76 ± 0.08	5.15 ± 0.09		
	1315	5-23-68	5.71 ± 0.08	5.61 ± 0.08		
	1320	6-13-68	7.7 ± 0.1			
	1305	7-25-68	5.76 ± 0.09		4.53	3.33
	1320	8-15-68	2.83 ± 0.06	2.55 ± 0.06		

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
13	0900	6-8-67	7.05 ± 0.35		1.51	
	0935	6-28-67	9.1 ± 0.2	9.7 ± 0.2	6.18	5.91
	1200	7-27-67	20.4 ± 0.2	21.2 ± 0.2		
	1230	9-26-67	10.1 ± 0.1			
	1012	10-17-67	10.8 ± 0.1			
	0930	11-7-67	8.8 ± 0.1	9.8 ± 0.1		
	1400	11-30-67	8.8 ± 0.2			
	1315	12-21-67	7.6 ± 0.1	7.2 ± 0.1		
	1335	1-18-68	9.3 ± 0.1			
	1315	2-8-68	7.8 ± 0.1			
	1315	2-29-68	12.6 ± 0.1	12.1 ± 0.1		
	1310	3-21-68	8.3 ± 0.1			
	1305	4-11-68	8.3 ± 0.1			
	1330	5-2-68	7.9 ± 0.1			
	1300	5-23-68	7.4 ± 0.1	7.21 ± 0.09		
	1305	6-13-68	4.63 ± 0.08			
	1305	8-15-68	4.66 ± 0.08			
14	1200	6-6-67	1.17 ± 0.06	1.32 ± 0.07	1.09	0.99
	1215	9-26-67	9.9 ± 0.1		9.44	
	0945	10-17-67	6.50 ± 0.07		6.07	
	1030	11-7-67	8.3 ± 0.1			
	1500	11-30-67	5.9 ± 0.2			
	0915	12-27-67	7.1 ± 0.1			
	1320	1-18-68	5.3 ± 0.1			
	1405	2-8-68	6.6 ± 0.1			
	1405	2-29-68	4.55 ± 0.08			
	1515	3-23-68	5.61 ± 0.07	5.57 ± 0.06		
	1400	4-11-68	6.97 ± 0.09	6.80 ± 0.09		
	1400	5-2-68	4.17 ± 0.08		2.06	2.58
	1330	5-23-68	7.7 ± 0.1	7.9 ± 0.1		
	1340	6-13-68	3.2 ± 0.1			
	1400	6-27-68	7.09 ± 0.09			
	1350	7-25-68	5.90 ± 0.09	5.55 ± 0.09		
	1335	8-15-68	1.78 ± 0.04		3.03	2.97

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
15	1200	6-6-67	3.15 ± 0.16	3.46 ± 0.17	4.03	3.41
	1145	9-26-67	8.8 ± 0.1	9.2 ± 0.1		
	0927	10-17-67	8.8 ± 0.1			
	1045	11-7-67	11.5 ± 0.1			
	1440	11-30-67	9.5 ± 0.3			
	1400	12-21-67	9.1 ± 0.1			
	1300	1-18-68	4.9 ± 0.1			
	1350	2-8-68	6.41 ± 0.09	6.01 ± 0.09		
	1350	2-29-68	8.2 ± 0.1			
	1400	3-21-68	5.78 ± 0.08		5.27	
	1345	4-11-68	9.3 ± 0.1			
	1415	5-2-68	7.8 ± 0.1		7.49	6.36
	1345	5-23-68	8.6 ± 0.1	8.4 ± 0.1		
	1405	6-13-68	22.0 ± 0.2			
	1340	6-27-68	16.2 ± 0.2	15.0 ± 0.1		
	1330	7-25-68	13.5 ± 0.1		10.61	9.50
	1350	8-15-68	3.53 ± 0.05		4.32	4.01
16	1420	6-15-67	0.62 ± 0.03	0.61 ± 0.10	0.66	
	1100	9-12-67	1.14 ± 0.05	1.00 ± 0.03		
	0920	10-3-67	0.87 ± 0.05			
	0915	10-24-67	0.87 ± 0.04			
	1310	11-16-67	1.57 ± 0.05			
	1330	12-7-67	0.97 ± 0.04			
	0915	1-4-68	1.75 ± 0.05			
	1305	1-25-68	2.62 ± 0.06			
	1310	2-15-68	1.07 ± 0.04			
	1305	3-7-68	0.84 ± 0.04		1.02	
	1305	3-28-68	0.82 ± 0.03			
	1305	4-18-68	0.53 ± 0.03	0.50 ± 0.03		
	1310	5-9-68	0.66 ± 0.03			
	1310	5-30-68	0.58 ± 0.03			
	0945	6-18-68	0.50 ± 0.02			
	1015	7-18-68	1.53 ± 0.05		1.28	0.74
	1300	8-1-68	1.17 ± 0.04			
21	1345	6-15-67	0.72 ± 0.04	0.55 ± 0.06	0.80	
	0945	9-12-67	0.85 ± 0.04			
	1000	10-3-67	0.62 ± 0.03			
	1000	10-24-67	0.50 ± 0.03			
	1400	11-16-67	1.13 ± 0.03			
	1415	12-7-67	0.98 ± 0.03			

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
21	1000	1-4-68	1.11 ± 0.04			
	1350	1-25-68	1.77 ± 0.05			
	1345	2-15-68	0.60 ± 0.03			
	1345	3-7-68	0.66 ± 0.03			
	1345	3-28-68	0.69 ± 0.03	0.76 ± 0.03		
	1340	4-18-68	0.37 ± 0.02			
	1345	5-9-68	0.53 ± 0.03	0.56 ± 0.02		
	1345	5-30-68	0.43 ± 0.02			
	1015	6-18-68	0.54 ± 0.02	0.51 ± 0.02		
	1330	8-1-68	0.76 ± 0.03			
22	1405	6-15-67	0.58 ± 0.03	0.56 ± 0.03	0.67	
	1245	9-6-67	1.89 ± 0.06	1.91 ± 0.05		
	1330	9-28-67	1.36 ± 0.05			
	1415	10-19-67	1.50 ± 0.05			
	1030	11-14-67	2.27 ± 0.05	2.41 ± 0.05		
	1115	12-5-67	1.90 ± 0.03			
	1000	12-27-67	1.43 ± 0.05			
	1025	1-23-68	1.68 ± 0.04			
	1015	2-13-68	0.62 ± 0.02			
	1015	3-5-68	0.86 ± 0.06			
	1000	3-26-68	0.77 ± 0.02			
	1015	4-16-68	0.53 ± 0.02			
	1030	5-7-68	0.88 ± 0.03			
	1030	5-28-68	0.73 ± 0.03			
	0950	7-18-68	0.69 ± 0.03			
	1020	7-30-68	1.58 ± 0.04	1.54 ± 0.03		
	1020	8-20-68	2.65 ± 0.05	2.79 ± 0.05		
23	2200	6-22-67	0.88 ± 0.04	0.78 ± 0.05	0.81	0.75
	1200	9-6-67	4.11 ± 0.10	4.04 ± 0.06		
	1400	9-28-67	6.28 ± 0.09	6.45 ± 0.09		
	1345	10-19-67	7.2 ± 0.1			
	0945	11-14-67	12.7 ± 0.1			
	1045	12-5-67	4.99 ± 0.06			
	1315	12-29-67	2.02 ± 0.05			
	0950	1-23-68	2.60 ± 0.07			
	0940	2-13-68	1.16 ± 0.03			
	0935	3-5-68	1.60 ± 0.04	1.91 ± 0.06		
	0930	3-26-68	1.83 ± 0.04			
	0945	4-16-68	0.60 ± 0.02			

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)		
	hour	day	USAEC		SWRHL
23	0955	5-7-68	2.24 ± 0.06		
	0945	5-28-68	2.75 ± 0.07		
	1305	6-27-68	2.19 ± 0.05		
	1005	7-30-68	2.04 ± 0.04	1.88 ± 0.04	
	0940	8-20-68	3.23 ± 0.05		
24	1324	6-15-67	0.66 ± 0.04	0.59 ± 0.03	0.83
	1405	9-14-67	0.64 ± 0.02		
	1400	10-5-67	0.47 ± 0.03		
	1340	10-26-67	0.69 ± 0.03		
	1015	11-21-67	0.95 ± 0.04		
	0940	12-12-67	0.78 ± 0.03		
	0945	1-9-68	2.24 ± 0.06		
	0955	1-30-68	0.56 ± 0.03		
	0950	2-20-68	1.03 ± 0.04		
	0945	3-12-68	0.81 ± 0.02		
	0950	4-2-68	0.53 ± 0.02		
	0945	4-23-68	0.61 ± 0.02		
	0950	5-14-68	0.56 ± 0.02		
	0945	6-4-68	0.32 ± 0.02	0.30 ± 0.02	
	1320	6-20-68	0.66 ± 0.03		
	0930	7-23-68	1.34 ± 0.02	1.35 ± 0.03	
	0930	8-6-68	0.39 ± 0.04		
25	1320	6-21-67	1.28 ± 0.06	1.48 ± 0.05	1.83 1.54
	1430	9-14-67	0.64 ± 0.02		
	1430	10-5-67	0.29 ± 0.02	0.36 ± 0.02	
	1315	10-26-67	0.83 ± 0.04		
	0945	11-21-67	0.83 ± 0.04		
	1300	12-14-67	0.48 ± 0.02		
	0930	1-9-68	1.89 ± 0.05	2.00 ± 0.05	
	0935	1-30-68	0.52 ± 0.02		
	0930	2-20-68	0.83 ± 0.03		
	0925	3-12-68	0.93 ± 0.03		
	0935	4-2-68	0.74 ± 0.02		
	0930	4-23-68	0.63 ± 0.02		
	0930	5-14-68	0.83 ± 0.03		
	0925	6-4-68	0.28 ± 0.02		
	1300	6-20-68	0.47 ± 0.03		
	1025	7-23-68	1.09 ± 0.03		
	1030	8-6-68	1.41 ± 0.03		

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
26	1310	6-21-67	1.18 ± 0.05	1.72 ± 0.06	1.65	1.83
	1340	9-14-67	1.14 ± 0.04			
	1330	10-5-67	0.39 ± 0.03			
	1400	10-26-67	0.81 ± 0.03	0.84 ± 0.03		
	1030	11-21-67	0.79 ± 0.05			
	1000	12-12-67	0.73 ± 0.03	0.69 ± 0.03	0.60	0.66
	1015	1-9-68	2.21 ± 0.06			
	1010	1-30-68	0.52 ± 0.02			
	1010	2-20-68	1.07 ± 0.04			
	1000	3-12-68	0.75 ± 0.02			
	1005	4-2-68	0.41 ± 0.03			
	1005	4-23-68	0.58 ± 0.02	0.48 ± 0.02		
	1010	5-14-68	0.60 ± 0.02			
	1005	6-4-68	0.30 ± 0.02			
	1345	6-20-68	0.45 ± 0.02	0.50 ± 0.03		
	0950	7-23-68	0.48 ± 0.02			
	0950	8-6-68	1.21 ± 0.03			
31	0900	6-28-67	0.36 ± 0.03	0.53 ± 0.04	0.41	0.39
	0915	9-12-67	0.90 ± 0.04			
	1030	10-3-67	0.73 ± 0.04	0.61 ± 0.03		
	1020	10-24-67	1.57 ± 0.05			
	1425	11-16-67	1.61 ± 0.05			
	1430	12-9-67	0.58 ± 0.03			
	1020	1-4-68	1.11 ± 0.04	1.18 ± 0.04		
	1420	1-25-68	1.65 ± 0.05			
	1410	2-15-68	0.77 ± 0.03	0.79 ± 0.03		
	1400	3-7-68	0.65 ± 0.03		0.74	
	1410	3-28-68	0.82 ± 0.03			
	1400	4-18-68	0.57 ± 0.03			
	1415	5-9-68	0.75 ± 0.03			
	1405	5-30-68	0.77 ± 0.03			
	1030	6-18-68	0.73 ± 0.02			
	1245	8-13-68	3.37 ± 0.05	3.28 ± 0.05		
32	1345	7-6-67	0.38 ± 0.03	0.43 ± 0.02	0.78	0.34
	0915	9-19-67	1.74 ± 0.05	1.82 ± 0.04		
	0900	10-10-67	0.78 ± 0.03	0.71 ± 0.03		
	1030	10-21-67	0.86 ± 0.03			
	1305	11-23-67	0.54 ± 0.03			
	1330	12-14-67	1.26 ± 0.04			
	1300	1-11-68	1.23 ± 0.05			

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
32	1305	2-1-68	0.54 ± 0.03	0.55 ± 0.03		
	1300	2-22-68	0.55 ± 0.03			
	1310	3-14-68	0.59 ± 0.02			
	1300	4-4-68	0.43 ± 0.02			
	1305	4-25-68	0.67 ± 0.03	0.73 ± 0.03		
	1305	5-16-68	0.43 ± 0.02	0.46 ± 0.02		
	1305	6-6-68	0.19 ± 0.02			
	0930	6-25-68	1.10 ± 0.03			
	1400	8-8-68	0.50 ± 0.02			
33	1010	6-28-67	0.58 ± 0.05	0.63 ± 0.03	1.46	1.27
	1130	9-6-67	1.83 ± 0.06	1.66 ± 0.04		
	1345	9-28-67	2.91 ± 0.07			
	1330	10-19-67	2.59 ± 0.06			
	0930	11-14-67	4.5 ± 0.1			
	1030	12-5-67	1.96 ± 0.04			
	1020	12-27-67	1.59 ± 0.05			
	0930	1-23-68	1.63 ± 0.04			
	0925	2-13-68	0.89 ± 0.03			
	0915	3-5-68	1.04 ± 0.03			
	0910	3-26-68	1.32 ± 0.03			
	0925	4-16-68	0.50 ± 0.02			
	0940	5-7-68	1.06 ± 0.03	0.99 ± 0.03		
	0930	5-28-68	1.04 ± 0.04	1.05 ± 0.05		
	0930	7-18-68	4.01 ± 0.07			
	0945	7-30-68	1.56 ± 0.04			
	0920	8-20-68	0.95 ± 0.03			
34	0925	7-11-67	0.68 ± 0.06	0.62 ± 0.04		
	1445	9-21-67	0.83 ± 0.03			
	1420	10-12-67	0.83 ± 0.03			
	1445	11-2-67	0.66 ± 0.03			
	1045	11-28-67	0.97 ± 0.04			
	1430	12-16-67	0.86 ± 0.03			
	1034	1-16-68	2.09 ± 0.05	2.20 ± 0.08		
	1025	2-6-68	1.02 ± 0.03			
	1415	2-24-68	0.76 ± 0.03			
	1035	3-19-68	0.70 ± 0.02			
	1040	4-9-68	0.46 ± 0.02			
	1045	4-30-68	0.87 ± 0.02	0.75 ± 0.02		

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
34	1040	5-21-68	0.71 ± 0.03			
	1035	6-11-68	0.43 ± 0.03	0.50 ± 0.03		
	1430	8-8-68	0.72 ± 0.03	0.77 ± 0.03		
35	1145	7-6-67	0.52 ± 0.03	0.66 ± 0.05	2.54	1.14
	1315	9-14-67	0.62 ± 0.02	0.63 ± 0.03		
	1315	10-5-67	0.70 ± 0.03			
	1415	10-26-67	0.80 ± 0.03			
	1045	11-21-67	0.67 ± 0.04			
	1020	12-12-67	0.81 ± 0.02			
	1030	1-9-68	2.00 ± 0.06			
	1030	1-30-68	0.52 ± 0.02			
	1025	2-20-68	0.88 ± 0.04			
	1015	3-12-68	0.76 ± 0.02			
	1025	4-2-68	0.52 ± 0.02			
	1020	4-23-68	0.52 ± 0.02			
	1030	5-14-68	0.61 ± 0.02			
	1020	6-4-68	0.32 ± 0.01			
	1400	6-20-68	0.46 ± 0.02	0.48 ± 0.02		
	1005	7-23-68	1.43 ± 0.03			
	1010	8-6-68	2.07 ± 0.04			
36	1127	7-6-67	0.38 ± 0.02	0.46 ± 0.04		
	1015	9-12-67	0.95 ± 0.04			
	0940	10-3-67	0.88 ± 0.04			
	0940	10-24-67	0.82 ± 0.04	0.73 ± 0.04		
	1330	11-16-67	1.28 ± 0.04		0.65	0.54
	1345	12-7-67	0.98 ± 0.03			
	0935	1-4-68	0.99 ± 0.03			
	1330	1-25-68	1.91 ± 0.06	1.89 ± 0.05		
	1325	2-15-68	0.75 ± 0.03			
	1320	3-7-68	0.49 ± 0.03			
	1325	3-28-68	0.72 ± 0.03			
	1320	4-18-68	0.36 ± 0.02			
	1330	5-9-68	0.49 ± 0.03	0.57 ± 0.03		
	1325	5-30-68	0.33 ± 0.03			
	1000	6-18-68	0.51 ± 0.02			
	1030	7-18-68	1.14 ± 0.04	1.13 ± 0.04		
	1315	8-1-68	0.78 ± 0.03			

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)		
	hour	day	USAEC		SWRHL
41	0940	7-11-67	0.47 ± 0.05	0.54 ± 0.04	1.95
	1030	9-19-67	0.96 ± 0.03	1.13 ± 0.06	
	1045	10-10-67	0.76 ± 0.03		
	1130	10-31-67	1.14 ± 0.04		
	1425	11-23-67	0.44 ± 0.03		
	1030	12-19-67	0.52 ± 0.03		
	1405	1-11-68	1.24 ± 0.04		
	1430	2-1-68	0.51 ± 0.03		
	1400	2-22-68	0.78 ± 0.03	0.76 ± 0.04	
	1415	3-14-68	0.58 ± 0.02		
	1405	4-4-68	0.49 ± 0.02		
	1405	4-25-68	0.51 ± 0.03		
	1405	5-16-68	0.53 ± 0.03		
	1405	6-6-68	0.13 ± 0.01		
	1030	6-25-68	0.91 ± 0.03	1.10 ± 0.03	
	1330	8-8-68	0.83 ± 0.03	0.79 ± 0.03	
42	0942	7-25-67	0.65 ± 0.03	0.65 ± 0.02	
	0930	9-19-67	1.07 ± 0.04		
	0920	10-10-67	0.73 ± 0.03		
	1145	10-31-67	0.77 ± 0.03	0.76 ± 0.03	
	1330	11-23-67	0.53 ± 0.03		
	1345	12-14-67	0.58 ± 0.03		
	1315	1-11-68	1.10 ± 0.04		
	1320	2-1-68	1.13 ± 0.04		
	1315	2-22-68	0.59 ± 0.03		
	1325	3-14-68	0.61 ± 0.02	0.62 ± 0.02	
	1320	4-4-68	0.57 ± 0.03	0.52 ± 0.03	
	1325	4-25-68	0.27 ± 0.02		
	1325	5-16-68	0.69 ± 0.03		
	1325	6-6-68	0.34 ± 0.03		
	0950	6-25-68	1.05 ± 0.03		
	1020	8-15-68	0.49 ± 0.04		
43	0932	7-25-67	0.74 ± 0.04		
	1400	9-21-67	0.90 ± 0.03		
	1400	10-12-67	0.76 ± 0.03	0.73 ± 0.02	
	1420	11-2-67	0.60 ± 0.02	0.61 ± 0.03	
	1030	11-28-67	0.81 ± 0.03		
	1140	12-19-67	0.62 ± 0.03		
	1015	1-16-68	1.68 ± 0.04		2.01

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
43	1015	2-6-68	0.92 ± 0.03			
	1020	2-27-68	0.60 ± 0.02			
	1020	3-19-68	0.38 ± 0.02			
	1030	4-9-68	0.54 ± 0.02			
	1030	4-30-68	0.17 ± 0.01			
	1015	5-21-68	0.50 ± 0.02			
	1015	6-11-68	0.48 ± 0.03			
	1020	8-13-68	1.86 ± 0.04			
44	1530	7-20-67	0.47 ± 0.03	0.49 ± 0.03		
	1530	7-20-67	0.73 ± 0.04	0.69 ± 0.04		
	1005	9-24-67	0.69 ± 0.02	0.68 ± 0.03		
	1300	10-12-67	0.88 ± 0.03			
	1330	11-2-67	0.73 ± 0.03			
	9030	11-28-67	1.20 ± 0.03		0.89	
	0910	12-19-67	1.26 ± 0.05			
	0920	1-16-68	1.94 ± 0.04		2.10	
	0910	2-6-68	1.12 ± 0.03			
	0925	2-27-68	0.89 ± 0.03			
	0930	3-19-68	0.77 ± 0.02			
	0940	4-9-68	0.62 ± 0.02			
	0940	4-30-68	0.99 ± 0.03			
	0930	5-21-68	0.92 ± 0.03			
	0925	6-11-68	0.66 ± 0.04			
	0930	8-13-68	4.37 ± 0.06			
45	0900	7-11-67	0.82 ± 0.06	0.79 ± 0.05	1.08	1.18
	1000	9-19-67	1.60 ± 0.07			
	1030	10-10-67	0.79 ± 0.03			
	1110	10-31-67	1.12 ± 0.04			
	1350	11-23-67	0.52 ± 0.03			
	1415	12-14-67	0.80 ± 0.03			
	1335	1-11-68	1.33 ± 0.05	1.34 ± 0.05		
	1345	2-1-68	0.43 ± 0.03			
	1335	2-22-68	0.75 ± 0.03			
	1345	3-14-68	0.50 ± 0.02			
	1340	4-4-68	0.60 ± 0.03	0.59 ± 0.02		
	1345	4-25-68	0.61 ± 0.03	0.57 ± 0.03		
	1345	5-16-68	0.87 ± 0.03			
	1345	6-6-68	0.40 ± 0.02	0.47 ± 0.02		
	1015	6-25-68	0.77 ± 0.02			
	1300	8-8-68	0.98 ± 0.03			

Table 1. Concentrations of radon 222 found in 48-hour integrated air samples from Grand Junction, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)	
	hour	day	USAEC	SWRHL
46	1800	7-20-67	0.51 ± 0.04	0.43 ± 0.04
	1330	9-21-67	0.48 ± 0.02	
	1320	10-12-67	0.66 ± 0.03	
	1400	11-2-67	0.78 ± 0.03	
	0947	11-28-67	0.79 ± 0.03	0.84 ± 0.03
	0930	12-19-67	0.80 ± 0.05	
	0945	1-16-68	2.08 ± 0.06	
	0945	2-6-68	0.99 ± 0.03	
	0950	2-27-68	0.84 ± 0.03	
	1000	3-19-68	0.49 ± 0.02	
	1000	4-9-68	0.47 ± 0.02	
	1000	4-30-68	1.04 ± 0.03	
	0950	5-21-68	0.39 ± 0.02	
	0950	6-11-68	0.44 ± 0.03	0.42 ± 0.03
	0950	8-13-68	0.35 ± 0.02	
47	1035	2-13-68	1.15 ± 0.03	
	1100	2-27-68	0.54 ± 0.02	
	1045	3-5-68	0.62 ± 0.02	
	1030	3-26-68	1.05 ± 0.02	
	1045	4-16-68	0.39 ± 0.02	
	1045	5-7-68	0.65 ± 0.02	0.62 ± 0.02
	1050	5-28-68	0.53 ± 0.03	
	1045	6-18-68	0.29 ± 0.02	
	1415	7-25-68	0.73 ± 0.03	
	1045	8-20-68	1.93 ± 0.04	

Location of radon sampling stations in Grand Junction, Colo.:

11 – 15	On and around Climax tailings pile
16	Grand Valley Rendering Company, 347 – 27½ Road.
21	Union Carbide Office, 1600 Ute Avenue.
22	Colorado State Patrol Garage, 606 South 9th.
23	LDS Bishop's Storehouse, 8th and Struthers Avenue.
24	John Cordray, 318 – 2/-3/8 Road.
25	Bert Wales, 1761 Palisade.
26	Duward Pifer, 287 Mountain View (Orchard Mesa).
31	Space Age Builders, 309 Pitkin Avenue.
32	Post Office, 4th and White Avenue.
33	Smith Chemical Company, 645 East 4th Avenue.
34	W. E. Bush, 2005 North 17th Street.
35	Ray Erickson, 2785 Laguna Drive.
36	Gerald Myers, 2795 D Road.
41	National Guard Shop, 325 West Avenue.
42	Richard Shay, 961 Chipeta.
43	John Barnes, 469 Sherwood Drive.
44	AEC Compound.
45	National Guard Armory, 428 – 28 Road.
46	Paul McKnight, 172 Shamrock (Orchard Mesa).

Table 2. Concentrations of radon 222 found in 48-hour integrated air samples from Durango, Colo.

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)		
	hour	day	USAEC	SWRHL	
51	1100	8-3-67		10.7	10.3
	2300	8-21-67		19.2	
	0630	9-19-67		13.3	
	0915	10-13-67		11.38	11.40
	0815	10-31-67		29.36	39.31
	0745	11-28-67		21.51	21.13
	1030	12-27-67		26.83	
	0800	1-16-68		28.97	
	0805	2-13-68		3.80	
	1000	3-8-68		14.13	
	0740	4-2-68		22.35	
	0750	4-26-68		23.67	
	1635	5-14-68		13.96	
	0820	5-30-68		21.37	
	0715	6-19-68		19.55	
	0440	7-17-68		12.90	10.13
52	1100	8-3-67		7.4	7.5
	0800	8-22-67		7.4	
	0630	9-19-67		32.0	
	0915	10-13-67		21.72	
	0825	10-31-67		9.20	
	1000	12-27-67		21.63	
	0755	1-16-68		23.10	
	0800	2-13-68		9.45	
	1005	3-8-68		12.82	
	0920	4-5-68		5.38	
	0740	4-26-68		0.48	
	0745	5-23-68		9.12	
	0745	5-28-68		7.96	
	0720	6-19-68		1.00	
53	0730	8-8-67	0.41 ± 0.03	0.70	
	0715	8-29-67		0.47	
	0720	9-26-67		0.42	
	0735	11-7-67		0.30	0.26
	0810	12-5-67		0.75	
	1500	1-1-68		0.44	
	0800	1-23-68		0.39	
	0800	2-6-68		0.34	
	1000	3-10-68		0.57	
	0840	4-16-68		0.30	

Table 2. Concentrations of radon 222 found in 48-hour integrated air samples from Durango, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
53	1130	5-12-68			0.73	
	0755	5-17-68			0.25	
	0830	5-30-68			0.54	
	0745	6-21-68			0.44	0.51
	0455	7-19-68			0.75	
54	0800	10-3-67			2.31	
	0825	10-27-67			1.84	
	0755	11-14-67			0.65	0.74
	0950	12-13-67			0.60	
	0800	1-30-68			1.94	
	1100	3-27-68			1.40	
	1425	4-18-68			0.44	
	1200	5-7-68			0.71	
	0800	6-9-68			1.62	
	0820	7-14-68			1.91	
55	0730	8-15-67			0.35	0.33
	0740	9-5-67	0.68 ± 0.03		0.44	0.43
	0730	9-12-67			1.28	
	0730	9-28-67			0.48	0.54
	0735	10-17-67			0.51	
	0735	11-21-67			0.68	
	0740	12-19-67			0.86	
	0805	1-30-68			0.60	
	0800	1-4-68			0.75	
	1015	2-16-68			0.41	
	0755	3-12-68			0.41	
	1050	4-11-68			0.39	
	0750	5-1-68			0.34	
	0740	5-23-68			0.11	
	0745	6-6-68			0.43	
	0750	7-2-68			0.51	
	1650	7-30-68	0.44 ± 0.05		0.24	0.10
56	0700	8-8-67	0.31 ± 0.03	0.31 ± 0.03	0.41	0.36
	0715	8-29-67	0.29 ± 0.03	0.29 ± 0.02	0.61	
	0715	9-26-67			0.47	
	0740	11-5-67			0.35	
	0800	12-7-67			0.62	
	0805	1-19-68			sample lost	
	0750	1-4-68			0.38	
	1025	2-16-68			0.45	

Table 2. Concentrations of radon 222 found in 48-hour integrated air samples from Durango, Colo. (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)		
	hour	day	USAEC	SWRHL	
56	0835	4-9-68		0.68	
	0730	4-23-68		0.37	
	0750	5-10-68		0.37	
	1200	5-26-68		0.22	
	0740	6-2-68		0.78	
	0750	6-21-68		0.44	
	0515	7-19-68	0.79 ± 0.06	0.66	0.64
57	0730	9-12-67		0.88	
	0740	9-28-67		0.44	
	0745	10-17-67		0.45	
	0750	11-21-67		1.15	
	0800	12-19-67		1.08	0.85
	0800	1-9-68		1.18	
	0745	1-30-68		0.51	
	0755	2-20-68		0.48	
	1035	3-25-68		0.56	
	1320	4-18-68		0.17	
	1155	5-12-68		0.26	
	0740	6-16-68		0.38	
	0810	7-14-68		0.19	
58	0745	10-3-67		0.90	
	0740	10-24-67		0.47	
	0740	11-14-67		0.28	
	1005	12-13-67		0.21	
	1515	1-1-68		1.28	
	0840	1-26-68		0.57	
	0830	2-6-68		0.69	
	1105	3-29-68		0.31	
	0720	4-23-68		0.09	
	0735	5-10-68		0.41	
	0735	6-6-68		0.21	
	0745	7-2-68		0.47	
	1705	7-30-68		0.19	0.13

Location of radon sampling stations in Durango, Colo.:

51	South side of tailings pile.
52	North side of tailings pile.
53	Richards Motel, Route 160 West.
54	Sewage Plant, 4th Avenue
55	Used car lot, 6th and 84th Streets.
56	State Patrol Garage, 6th Street.
57	Lumber Mill, Route 160 South.
58	Ballager Tire Service, 12th and Main.

Table 3. Concentrations of radon 222 found in 48-hour integrated air samples from Monticello, Utah

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
61	1245	8-8-67	5.13 ± 0.12		4.91	3.99
	1300	8-30-67	5.05 ± 0.1	5.20 ± 0.1	4.37	
	1000	9-28-67	4.8 ± 0.1	4.4 ± 0.1	4.36	3.22
	1000	10-19-67	4.2 ± 0.1		5.52	
	1000	11-9-67	5.9 ± 0.1		5.19	
	1000	12-1-67			2.27	
	1345	1-10-68			6.52	
	1100	2-3-68			3.75	
	1120	2-24-68			4.03	
	0820	3-13-68			1.64	
	1030	4-24-68			0.68	
	0930	4-5-68			2.77	
	1130	5-16-68			1.12	
	0930	6-4-68			8.11	
	0930	6-26-68			6.16	
	0930	7-15-68			3.47	
	0945	7-29-68			5.45	
62	1320	8-8-67	1.66 ± 0.08		2.33	1.70
	1015	9-28-67	2.32 ± 0.08		2.31	
	1015	10-19-67	3.4 ± 0.1		3.34	3.26
	0945	11-9-67			2.48	
	0900	12-1-67	3.2 ± 0.1		2.60	
	1330	1-10-68			4.41	
	1030	2-3-68			1.86	
	1145	2-24-68			3.38	
	0800	3-13-68			0.91	
	1015	4-24-68			1.83	
	1000	4-5-68			1.66	
	1115	5-16-68			0.55	
	0915	6-4-68			3.94	
	0915	6-26-68			1.07	
	0915	7-15-68			3.92	
63	1310	8-8-67	5.23 ± 0.10		4.23	4.92
	1030	9-28-67	5.2 ± 0.1		4.64	
	1030	10-19-67			4.61	
	0930	11-9-67	6.2 ± 0.1		5.21	
	0930	12-1-67	3.62 ± 0.07		2.75	
	1300	1-10-68	3.62 ± 0.07		4.12	
	1245	2-3-68			2.63	
	1200	2-24-68			11.99	

Table 3. Concentrations of radon 222 found in 48-hour integrated air samples from Monticello, Utah (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
63	0745	3-13-68			1.12	
	1030	4-5-68			1.76	
	1000	4-24-68			0.12	
	1100	5-16-68			1.06	
	0900	6-4-68			7.47	
	0900	6-26-68			5.34	
	0900	7-15-68			7.63	
	0900	7-29-68			5.78	
64	1345	8-8-67	3.79 ± 0.07		2.41	2.49
	1115	9-28-67	2.92 ± 0.08		2.75	2.81
	1045	10-19-67	3.4 ± 0.1		3.68	3.56
	1015	11-9-67			2.00	
	1030	12-1-67			2.17	
	1400	1-10-68			1.83	
	1300	2-3-68			4.08	
	1100	2-24-68			5.65	
	0730	3-13-68			0.89	
	0900	4-5-68			1.19	
	1045	4-24-68			1.23	
	1145	5-16-68			1.19	
	1000	6-4-68			4.47	
	1000	6-26-68			4.95	
	1000	7-15-68			5.25	
	1000	7-29-68			6.07	
65	1245	8-22-67			0.78	
	1000	9-7-67	0.60 ± 0.02		0.60	0.62
	1100	9-20-67	0.77 ± 0.04	0.81 ± 0.03	0.78	
	0945	10-12-67			0.77	
	0900	11-2-67			0.19	
	0800	11-23-67			0.46	
	0930	12-14-67			0.51	
	1000	12-28-67			0.62	
	1000	1-18-68			0.35	
	1000	2-13-68			0.31	
	0900	3-6-68			0.26	
	1030	3-28-68			0.32	
	0930	4-16-68			0.18	
	0715	5-8-68			0.24	
	0900	5-31-68			0.22	
	0900	6-18-68			0.54	
	0930	7-8-68			1.28	

Table 3. Concentrations of radon 222 found in 48-hour integrated air samples from Monticello, Utah (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRIL	
66	1245	8-15-67	0.65 ± 0.05	0.63 ± 0.04	0.37	0.52
	1030	9-7-67	0.42 ± 0.02		0.48	
	1130	9-20-67	0.54 ± 0.03		0.49	
	1000	10-12-67			0.48	
	0915	11-2-67			0.17	
	1000	11-25-67			0.12	
	1000	12-14-67			0.28	
	1200	1-25-68			0.59	
	1015	2-13-68			0.64	
	0930	3-6-68			0.59	
	1100	3-28-68			0.30	
	1000	4-16-68			0.25	
	0915	5-31-68			0.18	
	0915	6-18-68			0.31	
	1000	7-8-68			0.25	
71	1315	8-15-67	1.06 ± 0.05	0.47 ± 0.04	0.83	0.52
	1230	9-14-67	0.17 ± 0.02	0.21 ± 0.02	0.17	
	0945	10-5-67			0.19	
	1045	10-26-67			0.23	
	1130	11-14-67			0.11	
	1230	1-4-68			0.57	
	1115	1-25-68			0.43	
	1100	2-8-68			0.38	
	1030	2-28-68			0.28	
	1300	3-21-68			0.16	
	1100	4-9-68			0.10	
	1100	5-1-68			0.20	
	0915	6-11-68			0.37	
	0900	7-5-68			0.16	
	0930	7-23-68			0.28	
72	1345	8-15-67	0.50 ± 0.03	0.30 ± 0.04	0.52	0.52
	1200	9-14-67	0.16 ± 0.02.		0.16	
	0930	10-5-67			0.15	0.17
	1030	10-26-67			0.25	
	1115	11-14-67			0.25	0.17
	1130	12-7-67			0.18	
	1200	12-28-67			0.53	
	1030	1-19-68			0.23	
	1130	2-8-68			0.34	
	1100	2-28-68			0.28	

Table 3. Concentrations of radon 222 found in 48-hour integrated air samples from Monticello, Utah (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
72	1350	3-21-68			0.12	
	1115	4-9-68			0.11	
	1115	5-1-68			0.07	
	1030	5-24-68			0.15	
	0930	6-11-68			0.03	0.03
	0915	7-5-68			0.15	
	0915	7-23-68			0.26	
73	1400	8-15-67	0.48 ± 0.04	0.47 ± 0.04	0.37	0.44
	1130	9-14-67	0.13 ± 0.01		0.15	
	0915	10-5-67			0.33	
	1015	10-26-67			0.23	
	1145	11-14-67			0.06	
	1245	12-7-67			0.31	
	1015	12-28-67			0.57	
	1100	1-25-68			0.45	
	1015	2-8-68			0.46	
	1130	2-28-68	0.10 ± 0.01		0.19	0.21
	1045	4-9-68			0.10	
	1045	5-1-68			0.29	
	1015	5-24-68			0.16	
	1030	6-11-68			0.11	
	0930	7-5-68			0.59	
	1000	7-23-68			0.20	
74	1345	8-22-67			0.26	
	1100	9-14-67	0.17 ± 0.02		0.17	0.13
	0945	10-5-67			0.35	
	1000	10-26-67			0.28	
	1200	11-14-67			0.14	
	1230	12-7-67			0.18	
	1030	12-28-67			0.33	
	1030	1-25-68			0.59	
	1000	2-8-68			0.12	
	1200	2-28-68			0.33	
	1400	3-20-68			0.18	
	1030	4-9-68			0.06	
	1030	5-1-68			0.14	
	1100	5-24-68			0.21	
	0900	6-11-68			0.25	
	1000	7-7-68			0.38	
	0900	7-23-68			0.29	

Table 3. Concentrations of radon 222 found in 48-hour integrated air samples from Monticello, Utah (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
75	1315	8-22-67			0.87	
	1145	9-7-67	0.39 ± 0.02	0.34 ± 0.02	0.32	
	1200	9-20-67	0.43 ± 0.03		0.32	
	1015	10-12-67			0.35	
	0930	11-2-67			0.17	
	0830	11-23-67			0.29	
	1100	12-14-67			0.16	
	1245	1-4-68			0.55	
	1130	1-18-68			0.21	
	1030	2-13-68			0.28	
	1000	3-6-68			0.27	
	1130	3-28-68			0.18	
	0900	4-16-68			0.14	
	0930	5-31-68			0.14	
	0930	6-18-68			0.16	
	0900	7-8-68			0.37	
76	1330	8-22-67			0.49	
	1100	9-7-67	0.44 ± 0.03		0.49	
	1230	9-20-67	0.50 ± 0.03		0.43	0.45
	1030	10-12-67			0.23	
	1000	11-2-67			0.11	
	0845	11-23-67			0.38	
	1030	12-14-67			0.50	
	1200	1-4-68			0.94	
	1100	1-18-68			0.67	
	1100	2-13-68			0.35	
	1030	3-6-68			0.16	
	1200	3-28-68			0.23	
	0915	4-16-68			0.33	
	0745	5-8-68			0.22	
	1000	5-31-68			0.20	
	1000	6-18-68			0.47	
	0915	7-8-68			0.49	

Location of radon sampling stations in Monticello, Utah:

61 – 64	On tailings area.
65	Bailey Farm.
66	Southwest Gas Corporation tanks – 2d South.
71	Christenson's – 136 Uranium Drive.
72	Fire Station – 1st North.
73	Agriculture Building – 60 Center Street.
74	State Highway Check Station – Route 160 East.
75	Garage – 1st East and 2d South.
76	Sewage Plant.

Table 4. Concentrations of radon 222 found in 48-hour integrated air samples from Salt Lake City, Utah

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
81	1458	10-31-67	18.3 ± 0.1			
	1035	11-7-67	17.6 ± 0.2			
	1115	11-28-67			16.66	
	1600	1-4-68			5.70	
	1100	1-16-68	4.24 ± 0.05			
	1330	2-14-68			9.69	
	1135	3-6-68			6.92	
	1030	3-20-68			1.62	
	1115	4-17-68	2.55 ± 0.05			
	1100	5-1-68	11.5 ± 0.1			
	1145	5-28-68	7.8 ± 0.1			
	1505	7-11-68	16.2 ± 0.1	17.5 ± 0.1		
	1052	7-31-68	7.44 ± 0.08			
	1050	8-21-68	5.67 ± 0.08			
	1240	9-11-68			5.11	
	1005	10-3-68	22.1 ± 0.2	21.8 ± 0.1		
82	1245	10-27-67	5.9 ± 0.1		6.49	7.09
	1115	11-16-67	5.1 ± 0.1		7.42	7.34
	1025	12-27-67	4.4 ± 0.1			
	1120	12-5-67			2.26	
	1400	1-23-68			4.55	
	0740	2-7-68			3.49	4.39
	1110	2-28-68			2.49	
	1035	3-20-68			4.38	
	1050	5-7-68	4.17 ± 0.06			
	1115	4-9-68			2.97	
	1130	5-28-68	3.13 ± 0.08			
	1220	6-19-68			3.70	
	1100	7-24-68	6.39 ± 0.09			
	1205	8-7-68			5.20	
	1105	9-5-68			3.07	
83	0830	11-1-67			1.30	
	1035	11-21-67	0.39 ± 0.03			
	1115	12-12-67			0.50	
	1415	1-11-68	0.50 ± 0.02		0.26	
	1250	1-30-68			0.12	
	1340	2-20-68			0.39	
	1120	3-13-68	0.30 ± 0.02			
	1105	4-3-68	0.31 ± 0.02			
	1010	4-24-68	0.21 ± 0.01			
	1145	5-14-68	0.17 ± 0.01			

Table 4. Concentrations of radon 222 found in 48-hour integrated air samples from Salt Lake City, Utah (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)			
	hour	day	USAEC		SWRHL	
83	1140	6-5-68			0.63	
	1125	6-25-68			0.48	
	1000	7-18-68			0.60	
	1110	8-14-68			0.42	
	1100	8-28-68	0.71 ± 0.03			
	1530	9-18-68			0.09	
84	1200	10-29-67			0.76	
	1040	11-28-67	0.44 ± 0.02		0.38	
	1100	11-7-67			0.23	
	0945	12-20-67	0.42 ± 0.03			
	1040	1-16-68			0.85	
	1125	3-6-68	0.21 ± 0.02			
	1045	3-20-68	0.25 ± 0.02			
	1140	4-17-68			0.27	
	1110	5-1-68			0.31	
	1125	5-21-68			0.43	
	1130	6-11-68	0.21 ± 0.01			
	1040	7-31-68			0.28	
	1110	8-21-68			0.24	
	1255	9-11-68			0.39	
	1235	9-25-68	0.68 ± 0.02	0.53 ± 0.02	0.60	
	1020	10-9-68			1.23	1.05
85	1122	10-29-67	0.60 ± 0.02			
	1050	11-16-67			0.63	0.58
	1130	12-5-67			0.36	0.33
	1155	1-23-68	0.98 ± 0.04			
	0755	2-7-68	0.83 ± 0.04	1.00 ± 0.04		
	1135	3-6-68	0.23 ± 0.02			
	1015	3-27-68	0.58 ± 0.02			
	1100	4-9-68	0.81 ± 0.02			
	1030	5-7-68	0.82 ± 0.03			
	1120	5-28-68	0.47 ± 0.03			
	1055	6-19-68	0.51 ± 0.02			
	1150	7-24-68			0.62	
	1020	10-3-68	1.30 ± 0.03	1.44 ± 0.05	1.4	
86	1315	10-29-67			0.50	
	1045	11-21-67	0.44 ± 0.02			
	1125	12-12-67			0.15	
	1547	1-3-68	0.54 ± 0.03			

Table 4. Concentrations of radon 222 found in 48-hour integrated air samples from Salt Lake City, Utah (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)		
	hour	day	USAEC		SWRHL
86	1305	1-30-68			0.11
	1310	2-20-68	0.23 ± 0.01		
	1045	3-13-68			0.31
	1120	4-3-68			0.28
	1050	4-24-68			0.17
	1100	5-21-68	0.30 ± 0.02		
	1130	6-5-68	0.15 ± 0.02	0.17 ± 0.01	
	1110	6-25-68	0.29 ± 0.02		
	1030	7-18-68	0.51 ± 0.04		0.32
	1305	8-14-68			0.17
	1100	8-28-68	0.20 ± 0.01	0.19 ± 0.02	
91	1117	10-27-67	0.38 ± 0.02		
	1025	11-7-67			0.17
	1105	11-28-67			0.99
	1005	12-20-67			0.48 0.46
	1110	1-16-68	0.69 ± 0.04	0.73 ± 0.05	
	1255	2-14-68			0.61
	1155	3-6-68			0.27
	1100	3-20-68			0.80
	1045	4-17-68	0.18 ± 0.02	0.17 ± 0.01	
	1040	5-1-68			0.24
	1150	5-21-68			0.26
	1125	6-11-68			0.24
	1105	7-8-68	0.99 ± 0.04		
	1045	8-21-68			0.15
	1220	9-11-68	0.22 ± 0.01	0.20 ± 0.02	
92	1550	10-31-67			0.42
	1025	11-14-67			0.82
	1105	12-5-67	0.21 ± 0.01	0.26 ± 0.01	
	1055	12-27-67			0.84
	1415	1-23-68			0.85
	1110	2-28-68			0.42
	1100	3-27-68	0.26 ± 0.01		
	1020	4-9-68	0.23 ± 0.01		
	1120	5-7-68			0.29
	1230	5-28-68			0.22
	1215	6-19-68	0.40 ± 0.02		
	1130	8-7-68	0.30 ± 0.01	0.22 ± 0.02	
	1150	9-5-68	0.40 ± 0.02	0.45 ± 0.03	
	1530	9-18-68			0.17
	0945	10-3-68			0.26

Table 4. Concentrations of radon 222 found in 48-hour integrated air samples from Salt Lake City, Utah (continued)

Station no.	Midpoint of sampling time		Concentration of radon 222 (pCi/liter)		
	hour	day	USAEC		SWRHL
93	1450	10-31-67	0.55 ± 0.02		
	1045	12-12-67	0.25 ± 0.02		
	1335	1-11-68	0.25 ± 0.02		
	1335	1-30-68	0.19 ± 0.02		
	1335	2-20-68	0.16 ± 0.01		
	1115	3-13-68			
	1005	4-24-68			0.22
	1100	4-3-68			0.06
	1145	5-14-68			0.25
	1120	6-5-68			0.07
	1045	6-25-68	0.30 ± 0.02		0.20
	1000	7-18-68	0.38 ± 0.02	0.42 ± 0.02	
	1115	7-31-68	0.20 ± 0.01		
	1045	8-28-68			
	0900	10-5-68			0.26
					0.54
94	1427	10-27-67	0.58 ± 0.03	0.60 ± 0.02	
	1000	11-7-67	0.83 ± 0.03	0.95 ± 0.04	
	1122	11-28-67	0.57 ± 0.03		
	1010	1-16-68			
	1225	2-14-68	0.60 ± 0.03		0.94
	1045	3-13-68	0.17 ± 0.02		
	1135	3-20-68			
	0945	4-17-68			0.46
	1125	5-1-68	0.29 ± 0.02		0.13
	1035	5-21-68	0.07 ± 0.01		
	1040	6-11-68	0.24 ± 0.01		
	1050	7-2-68			
	1025	7-31-68			0.50
	1000	8-21-68	0.14 ± 0.01	0.12 ± 0.02	0.37
	1235	9-11-68	0.24 ± 0.01	0.29 ± 0.02	
	1200	9-25-68	0.69 ± 0.02	0.71 ± 0.03	
	1000	10-9-68	0.55 ± 0.03	0.57 ± 0.03	
95	1000	11-14-67	0.52 ± 0.02		
	1047	12-5-67	0.20 ± 0.01		
	1055	1-23-68	0.58 ± 0.03		
	0825	2-7-68	0.58 ± 0.03		
	1130	2-28-68	0.32 ± 0.02		
	1015	3-20-68			
	1050	4-9-68			0.17
	1040	5-7-68			0.22
					0.19

Table 4. Concentrations of radon 222 found in 48-hour integrated air samples from Salt Lake City, Utah (continued)

Station no.	Midpoint of sampling time: hour	day	Concentration of radon 222 (pCi/liter): USAEC		SWRHL	
95	1120	5-28-68			0.21	
	1045	6-19-68			0.21	
	1350	7-11-68			0.20	
	1100	7-24-68			0.28	
	1205	8-7-68	0.20 ± 0.02	0.19 ± 0.01		
	1300	8-14-68	0.10 ± 0.01	0.16 ± 0.04		
	1030	8-28-68			0.21	
	1435	9-18-68	0.14 ± 0.01	0.16 ± 0.02		
96	1417	10-29-67	0.16 ± 0.01			
	1045	11-21-67			0.15	
	1155	12-12-67	0.17 ± 0.02			
	1200	1-7-68			0.45	
	1400	1-30-68	0.12 ± 0.01			
	1320	2-20-68			0.21	
	1225	3-13-68	0.12 ± 0.01	0.12 ± 0.01		
	1205	4-3-68	0.17 ± 0.01			
	1155	5-14-68	0.06 ± 0.01			
	1235	6-5-68	0.09 ± 0.01			
	1145	6-25-68			0.24	
	0915	7-18-68	0.22 ± 0.02	0.42 ± 0.03	0.38	0.31
	1200	8-14-68	0.25 ± 0.02			
	1525	9-25-68			0.44	
	2230	10-8-68	0.28 ± 0.02	0.27 ± 0.02		

Location of radon sampling stations in Salt Lake City, Utah:

81 Center of tailings (700 West 3300 South).
82 Sewage Plant, 650 West 3300 South.
83 American Smelting & Refining Company, Hygiene & Research Department, 3422 South 7th West.
84 D. B. Harmon, 1080 West 3300 South.
85 Bonneville News Company, 965 Beardsley Place.
86 J. A. Skogg, 1501 West Claybourne Avenue.
91 D. Bolton, 570 West 3740 South.
92 Chris Body and Paint Shop Inc., 3152 South 2d West.
93 Tuloma Gas Products Co., 201 West 27th South.
94 Aluminum Manufacturing & Supply Co., 1809 South 8th West.
95 A. H. Higham, 105 Westwood Avenue.
96 Salt Lake City Health Department, 610 South 2d East.

The following samples were taken on the covered tailings at the old mill site east of Rifle, Colo.:

	Midpoint		pCi/liter
Northwest corner	1220	8-27-68	32.8
Southwest edge[a]	1215	8-27-68	23.8

[a]Downwind for night time inversion conditions.

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